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AMERICAN WELDING SOCIETY
ESTABLISHED 1919
JOURNAL

Volume 4 October, 1925 Number 10

DISCUSSION OF PAPERS

Every member who plans to attend the fall meeting in Boston is expected to participate in the discussion of the technical papers which will be presented at the various sessions. These papers are printed in this issue. Discussions, if possible, should be prepared in advance. These discussions will be printed in the November and December issues of the JOURNAL.

It is the duty of every member to contribute whatever information he has on these several subjects in question.

MEMBERSHIP

An examination of the various papers published in this issue indicates that welding is saving thousands of dollars annually in a great many industries. It is rapidly replacing riveting as a method of fabrication. All of the manufacturers who are now using welding in their production work concede that welding is on the upgrade and that we may confidently expect that within a few years its use will be the rule rather than the exception to the rule.

It is interesting to compare the volume of welding that is being done today as compared with that before the advent of the American Welding Society. Figures compiled several years ago by the American Bureau of Welding, based upon the amount of welding wire sold by a number of companies, indicated that such applications had more than doubled during the two years of the existence of the Society. The Society may in a small measure be accredited with this achievement but it is largely due to the growing confidence in welding.

Before welding will be used universally, a great deal of educational work must be done in convincing legislators, engineers and executives that welding is a dependable process, that it can be properly controlled and that the work can be inspected and tested. A great deal of information is also needed by the various engineers in designing their product for the use of welding.

In order to carry on this educational work and to secure and disseminate reliable information on welding, there was organized in 1919 the American Welding Society. The future and growth of the Society is therefore intimately interwoven with the growth of the welding industry. The Welding Society serves as a clearing house of technical information in the welding field. In order to keep abreast of latest developments, it is necessary for those identified with the welding industry to be affiliated with the American Welding Society.

Probably one of the greatest factors in the development of welding and the extension of its use is the research department of the American Welding Society known as the American Bureau of Welding. Many reports have already been issued by the Bureau and published in the JOURNAL of the Society. A great deal of investigational work is now under way and still more will be shortly undertaken. Methods, technique, materials and apparatus are constantly changing as new scientific facts are discovered.

An information service is maintained by the Society to supply technical and research information to members concerning specific problems. Membership in the American Welding Society is an opportunity which cannot be overlooked by anyone identified with the welding industry.

PRESSURE VESSELS

As announced in the last issue, the American Bureau of Welding will shortly undertake a comprehensive series of investigations to secure further information needed by the American Welding Society and the American Society of Mechanical Engineers in bringing about additions and revisions in the present code on unfired pressure vessels. These investigations will include tests to destruction of a large number of tanks fabricated by

the gas and electric welding processes using single vee, double vee, lap welded and other types of joints. It will also include tests on large tanks and tanks made of heavy material. In addition, there will be a carefully prepared series of tests to determine fatigue strength of different types of welded joints.

National Research Council has agreed to act as treasurer of the funds. About $20,000 will be raised in cash. Estimates of the contributions of services, materials and tanks show that the total cost of the investigation will be well over $100,000. A greater part of these investigations will be carried out at the Bureau of Standards. Prof. H. L. Whittemore has been selected as chairman of the committee which will have the immediate work in charge.

Tank manufacturers who are interested in this investigation and wish to cooperate should get in touch at once with the secretary of the American Bureau of Welding.

WELDED RAIL JOINTS

The Executive Committee of the Welded Rail Joint Committee held a meeting in Washington on Oct. 8.

Welding was started in connection with a series of tests which will be made on a number of typical welding wires used by the street railway industry. Test specimens are being made by welding together (a) two plates of 0.20 carbon, (b) two plates of 0.75 carbon and (c) one plate of 0.20 carbon with a plate of 0.75 carbon. Expert welders in the use of metal arc welding, carbon arc with the "hand feed system" and carbon arc with the "rod in position system" are being used for these tests.

At the meeting of the Executive Committee it was definitely decided to embark upon a series of investigations using the telemeter to determine actual stresses which occur in the seam welded joints in the track under unusually severe conditions. A better knowledge of the stresses will enable engineers to design joints which will last longer in service.

GAS WELDING COMMITTEE BEING REORGANIZED

Very recently Professor C. A. Adams, Director of the American Bureau of Welding, appointed a small Executive Committee to constitute a nucleus of a larger gas welding research committee of the Bureau. Mr. S. W. Miller was selected as the chairman. This Executive Committee held a meeting in New York on Oct. 6. Several important problems to the industry were selected for study. These problems will be assigned to appropriate sections of the country. The Executive Committee plans to hold regular meetings to review progress.

EMPLOYMENT SERVICE BULLETIN

Opportunities.—The Society is glad to learn of desirable opportunities from responsible sources, announcements of which will be published without charge in the BULLETIN.

Services Available.—Under this heading brief announcements (not more than seventy-five words in length) will be published without charge to members. Announcements will not be repeated except upon request received after an interval of three months; during this period, names and records will remain in the office reference files.

Note.—Copy for publication in the BULLETIN should reach the Society's Office not later than the thirtieth of the month if publication in the following issue is desired. *ALL REPLIES should be Addressed to the number Indicated in Each Case and Mailed to Society Headquarters.*

Services Available

A-38. Welder desires position. Acetylene welder of 10 years' experience desires to make change. Capable of taking charge of welding operations. Reference given as to ability and character. Have business experience and can make shop trade expand.

A-39. Acetylene welder desires position. Have had six years' experience in welding and brazing of all metals. Have been connected with the Todd Engineering Co., The Westchester and Lighting Co., and the National Transit Pump and Machine Co. Can give references.

Gas Welding of Power Plant Piping in Shop and Field*

By A. W. Moulder†

From a practical standpoint the possibilities of welding in the field of power plant piping are as broad as the field itself.

Large as is the aggregate amount of welding that has already been done in this field, both in the way of headers and in the way of pipe lines welded on the job, that aggregate does not even approach the amount that the many advantages of welding should produce.

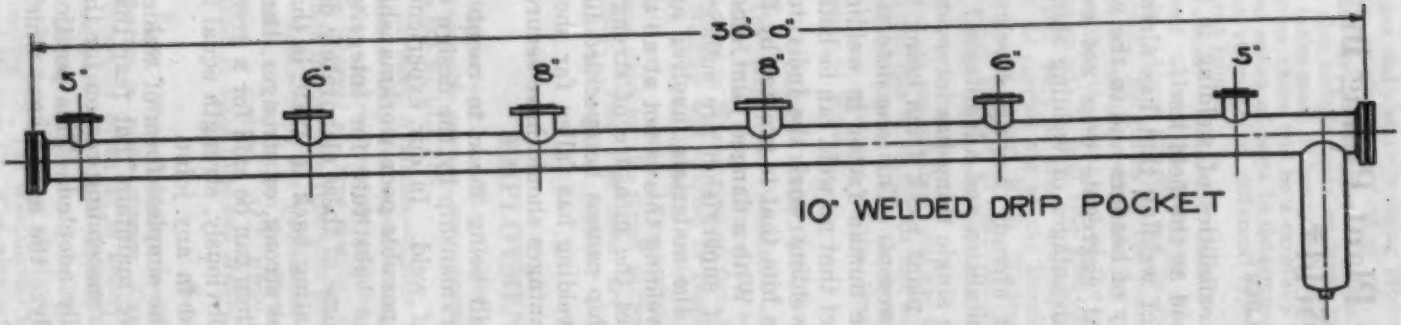
What has prevented welding from already having developed more nearly up to the limit of its possibilities and advantages?

In the opinion of the writer only one single thing has intervened to keep all-welded pipe lines in power plant work from being the rule rather than the exception as at present. This one deterring consideration is the importance of the human factor in welding. Because of that human factor, it is a fact that no weld can be better than its welder. In other words, in welding work the individual workman has a responsibility put upon him that is greater by far than in any other similar type of work. With a flanged joint, elbow grease and even a moderate amount of supervision are sufficient to assure the joint being as strong as the materials involved and the design followed will allow. With welding this is not at all the case. Quality of workmanship becomes the measure of strength and reliability and because workmanship cannot be specified like weight of pipe or strength of fitting, welding has fallen far short of the wider uses its unquestioned advantages should have secured for it.

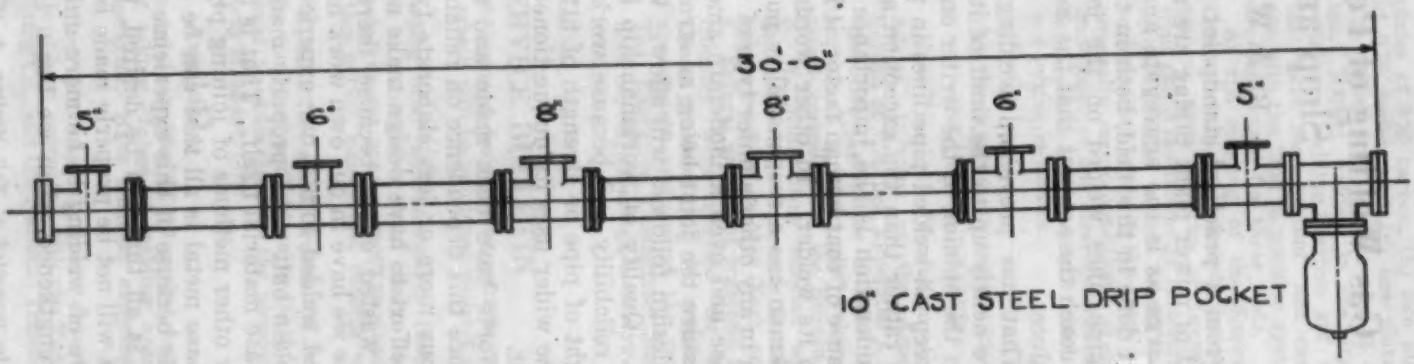
Efforts have been made and are still being made to counterbalance this dependence on reliable workmanship by the design of various more or less elaborate types of weld. In our experience this effort to have design make up for possible poor workmanship is a wasted effort because there is no substitute for integrity. While we have in our own work made some of these elaborately designed welded joints, our experience, dating back to 1910, is that the plain butt weld, properly made, is as strong, or stronger, than the base material itself. That is more than can be said for a great many other methods of joining pipe. Obviously, strength equal to the base metal is all that can be desired in any joint.

It is because of this experience that the simplest form of welded joint is all that can be desired, that we maintain that fear that welds will not be properly made is the transcending reason for the failure of welding to be more universally adopted. This position is strengthened when we begin to analyze the advantages which

*To be presented at Fall Meeting, A. W. S., Boston, October, 1925.
†Chief engineer, Heating, Power and Industrial Piping Division, Grinnell Co., Inc.



10" Steel pipe header welded nozzles with lap joint flanges.



10" Steel pipe header with lap joint flanges and X.H. cast steel tees

Fig. 1.

are inherent to welding when it is properly done. To illustrate this let us assume for a moment that dependable workmanship could be counted on as definitely and regularly as the strength of a specified piece of pipe or weight of fitting and on that basis discuss the various advantages which come from a liberal use of welding in power work, both in the field and in the shop.

Welding of power plant piping has many advantages most of which are relatively applicable whether the system is only partially welded as for example the headers or whether the system is welded as nearly as possible in its entirety. Up to date the great bulk of power plant welding has been fabricated in the shops of regular manufacturers engaged in that work. Some of these same concerns have, during recent years, successfully carried welding right into the power plant itself by doing pipe line welding on the job. This latter development has grown quite rapidly, in some few cases having been carried to the extent of eliminating, on some lines, practically all fittings and providing flanges only adjacent to valves and apparatus.

The first advantage is lower first cost. I find in a review of the records of this Society on the subject of pipe welding considerable data covering the relative first cost of an individual welded joint as against an individual coupled or flanged joint. I find very little, however, giving the relative over-all cost of fittings and flanged piping.

To illustrate the relative first cost of two simple headers which might be incorporated in the design of any small power plant I am showing Fig. 1 which in the one case illustrates a welded high pressure steam header for a battery of several boilers and with outlets for several connections to turbines, etc. With the dimensions and materials shown on the sketch the cost of this welded header would be $332.00. The other illustration in Fig. 1 is that of a header for the same purpose but made up of the same weight steel pipe with lap joint flanges and extra heavy cast steel fittings. The cost in this case is $1,034.00.

Fig. 2 shows a large low pressure exhaust steam header, in the one case made up welded and in the other case made up with lap joint piping and cast iron flanged fittings. The welded header would cost $269.00. As shown with flanges and flanged fittings, the cost would be $478.00.

These startling differences in price probably explain why there has been a more rapid development of welding in headers and allied work than in other pipe runs in power plant work, since the saving is largely proportional to the number of flanged fittings and joints. Even when fewer joints are involved the saving is still substantial, particularly in view of other advantages to be discussed later.

In the case of Fig. 1, there is also a saving in weight of 2980 lbs. and in the case of Fig. 2 a saving of 3530 lbs., both in favor of

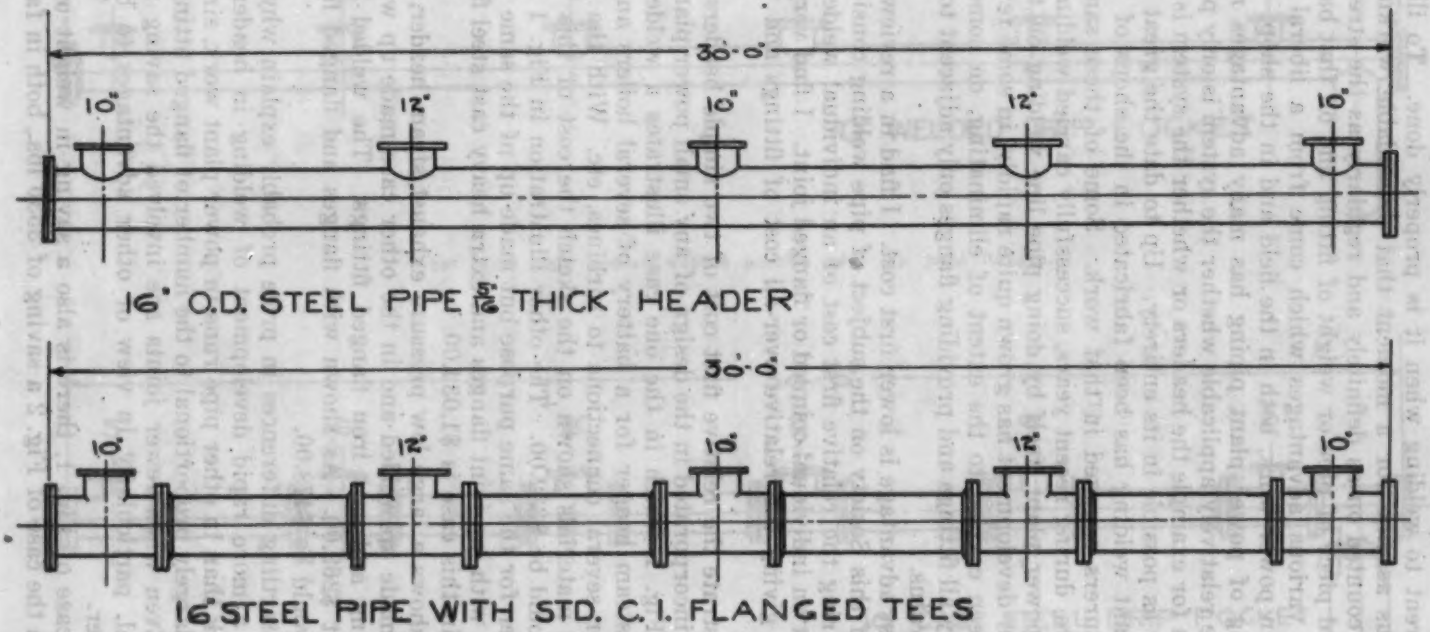


Fig. 2. Comparison of welded exhaust header with one having cast iron flanged fittings.

the welded headers. This naturally means a relative saving in labor of handling and installation so that the entire saving is not shown simply in difference in price.

These savings in first cost apply to work that is almost invariably done in the shop. The question naturally arises as to whether such savings can be made in field work where the facilities for welding are not so good. The answer to this question is best given by the following figures covering an actual job we installed for a large western manufacturer. This job was the installation of 875 feet of 16 inch O.D. steel pipe installed in a concrete tunnel.

The following shows actual cost as installed with 43 butt weld joints and 20 standard rolled steel flanges, used adjacent to valves and expansion joints.

16-inch O.D. Steel Pipe, ¼ inch thick, 875 feet	$2,062.90
Mill Shipment Freight	153.55
16-inch Standard Weight Rolled Steel Flanges, 20	386.16
16-inch Red Rubber Gaskets, 20	30.00
1 x 4 Bolts and Hex Nuts, 320	53.13
Drums Acetylene Gas, 30	193.20
Drums Oxygen Gas, 45	163.25
Welding Steel, 100 lbs	16.50
Total Cost	$3,058.69

The following shows the actual cost of materials if lap joint piping had been furnished from one of our fabricating plants.

16-inch O.D. Steel Pipe, ¼ inch thick, 875 feet	$2,394.44
Fabricating Plant Cost	
Freight from Fabricating Plant	233.10
16-inch Lap Joints with Standard C.I. Flanges, 88	1,306.80
16-inch Red Rubber Gaskets, 63	94.50
1 x 4½ Bolts and Hex Nuts, 1008	175.02
Total Cost	$4,203.86

The above figures show that in this instance the material fabricated for lap joints and delivered to the job would have cost approximately 37 per cent more than the materials for the job as installed with welded joints.

The actual cost of labor for handling the pipe (through one opening in the tunnel) including the foreman's time, welder's time and fitters and helpers, totalled 440 hours. The foreman who handled the job expressed the opinion that the labor for lap joint piping would have been about the same, but mentioned the fact that the plain end pipe was easier to handle in the tunnel than lap joint piping would have been, due to the fact that the pipe roll supports were placed in position and it was then very easy to roll the pipe through the tunnel on these rollers.

There is also a considerable saving in first cost due to the heavy expense of insulating flanges. With welded piping many flanges are eliminated and a more economical job of pipe covering is

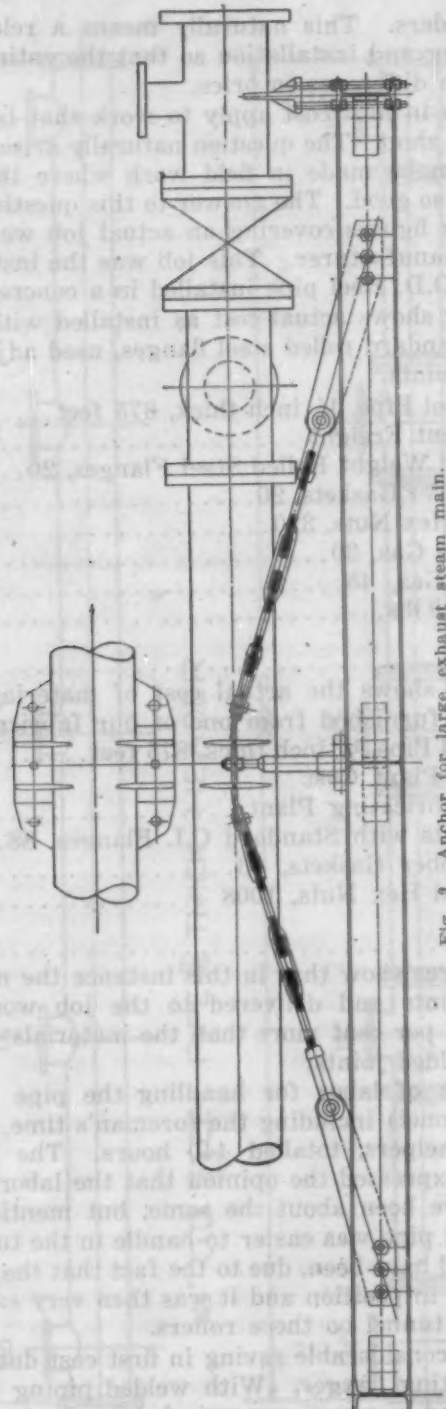


Fig. 3. Anchor for large exhaust steam main.

obvious. In fact the great difficulty of adequately insulating large flanges often results in their being left uncovered with consequent serious heat losses. In some cases flanges are also left uncovered to facilitate repairs and replacement of gaskets.

The extent of the savings by having a perfectly insulated line have been demonstrated by the engineers of the Super-Heater Co., the record of whose tests, presented before the A.S.M.E., showed that a pipe with bare flanges, but insulated along the body of the pipe lost half as much heat as did a totally bare pipe.

Another economic factor which is particularly apparent in large lines for low pressure work is the saving in weight of the pipe itself. This saving in weight is greater, of course, where screwed flanges are used because often the weight of pipe is beyond what is necessary in order to provide for threads. Where pressure factors are not involved, engineers by specifying welding would of

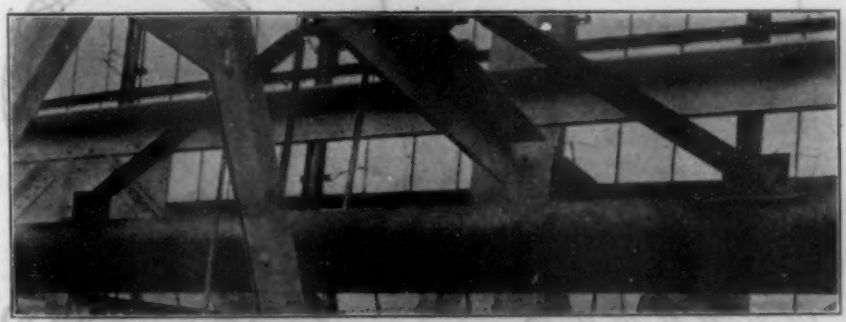


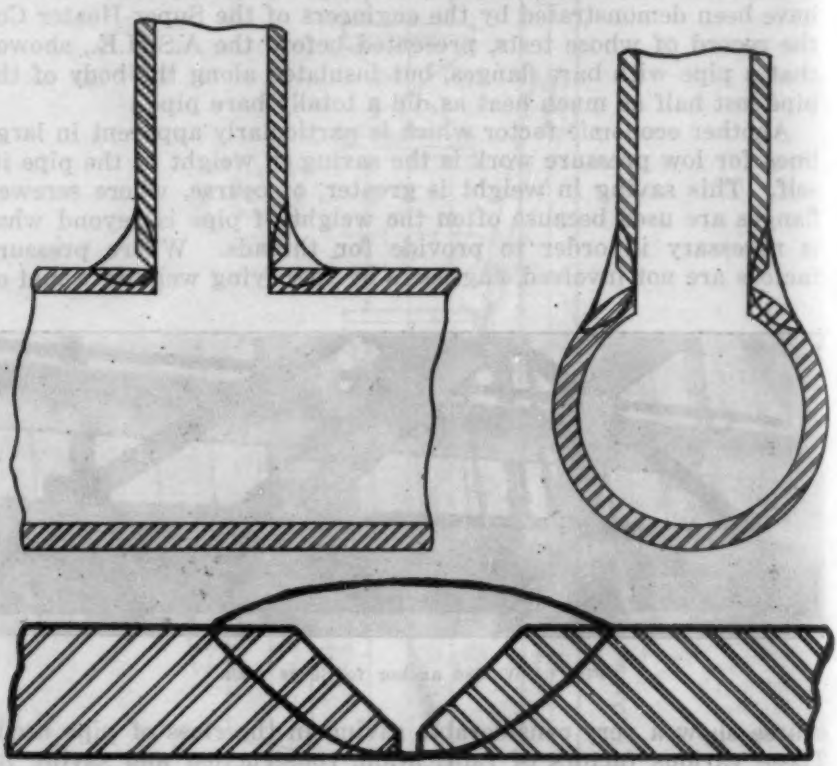
Fig. 4. Welded anchor for large main.

course show a very considerable saving in the class of pipe used. These various factors of fabrication, construction and saving in materials combine to make welding under a great many conditions a very much lower first cost proposition than other types of joints. More important still, these savings are made with an increase of efficiency if the welds specified are properly made.

Perhaps of even greater importance than the money saving, where all or part of the welding is done on the job, is the improved service which such procedure allows the contractor to give. If all piping must be fabricated to exact length, as is the case unless welding on the job is done, it means that measurements for a portion of the piping at least cannot be taken unless the apparatus, such as boilers, turbines and auxiliaries are in place and lined up. It is then necessary to order these materials, get them fabricated and ship them often at an extra added expense and with consequent actual delay in time of starting of the power plant.

For the high pressure and high temperature lines where cast steel fittings are usually required another element which has an important bearing on service enters into the proposition.

As you know the manufacture of steel fittings and cast steel headers is a somewhat speculative undertaking. The several fittings and headers of this kind required for a given job may be ordered weeks and sometimes months in advance. When finally cast there is always present the possibility that one or more cast-



Figs. 5 and 6. Standardized preparation of material for welding.

ings will be found defective and will tie up the entire job. Defects in the casting may not become apparent until machining operations are well along and often such defects do not show up until after the material is completely installed and tested. This feature often results in the discovering of defective material at the last moment with delays caused by reorders and remanufacture running to weeks and months.

Perhaps our first experience along this line was in a power job for the Rhode Island Company in Providence where several cast steel fittings were found to be defective after the work was almost entirely completed. We took the matter up with the engineer in charge and suggested that he allow us to make welded fittings from pipe instead of reordering the cast steel fittings with all that involved in the way of chance for another defective casting. He agreed and we successfully welded the special fittings. They have

given satisfaction for a period of 12 years on a line of 200 pounds pressure and 125 degrees superheat.

Even where cast steel fittings are not required this same element

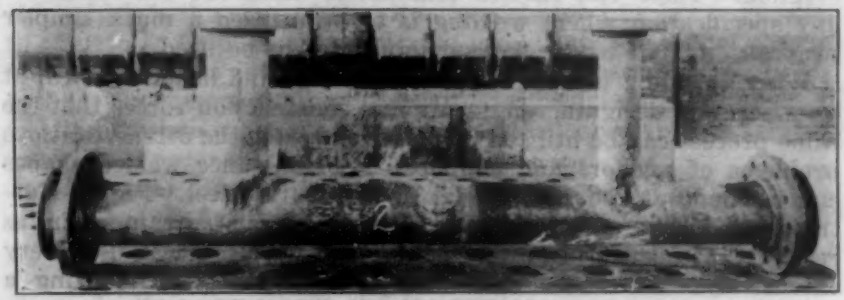


Fig. 7. Header before testing.

Fig. 8. Header after testing.

Fig. 9. Header after testing.

of delay is often present. An example of this is large condenser and exhaust steam piping where the cast iron fittings necessary almost invariably include some "specials."

In a word, there is in welding a flexibility which not only allows piping work to proceed in advance but also which allows many desirable changes to be made in the layout during the process of erection. These two factors combine to make the fabrication of any specification where welding is to be utilized a much simpler proposition than where flanged joints are to be used.

Where welding is being employed in lines and headers it will at once occur to designing engineers and construction forces that the same process can be utilized to greatly simplify the often vexatious problems of anchors and supports. For instance welded shapes can be made as required of flat or structural steel. Fig. 3 illustrates a design of anchor for a large exhaust steam main as recently installed in a power plant where welding was used very extensively. Reference is also suggested to Fig. 4 showing a typical anchor on the large main of the Ford Motor Company in Chicago. This is part of an extensive Grinnell Hot Water Heat-

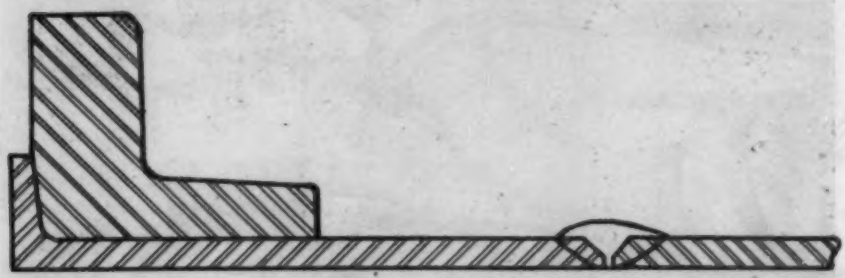


Fig. 10. Method of attaching flange.

ing System in that great plant where all mains from 7 inch to 16 inch totalling 5000 feet were butt-welded on the job. The welded anchor was constructed with a piece of angle iron welded to the top of the pipe which is clamped to the steel work with flat iron.

Still another advantage of welding is forcefully illustrated in large exhaust steam and condenser lines. Where these long runs are made with cast iron fittings, the tremendous weight set up becomes a structural problem of importance often involving special provision in the building to support the lines.

Another point very much in favor of welded piping for power plants is of course the fact of a much lower maintenance cost due to leaky joints. Where the power plant is serving industries or communities with power and light the leaking of a single flanged joint may cause shut down which will result in a considerable economic loss to the community. Always providing that the welding is properly done, it can be set down that once so done a joint can be forever forgotten which is certainly not the case with even the best of flanged joints.

All of the foregoing advantages are so real, so obvious and so important that the problem of removing the one single factor that

limits their wide extension to the whole field of power plant piping becomes one of transcending importance. As previously pointed out, the single restricting factor is the development and perfecting of some method to assure that absolute dependability of workmanship which is the crux of the situation. Later I have a suggestion to offer to accomplish that desirable end. But before that suggestion can be most intelligently discussed it is necessary to briefly outline the several factors that are involved in this problem of welding workmanship. All workmanship is based on four factors:

1—Proper materials.
   (a) Basically as to their inherent qualities.
   (b) Artificially as to their special preparation for the work involved.
2—Proper tools.
3—Proper methods and instruction.
4—Proper test to see that the failure of the human element does not destroy all the value of the preceding factors.

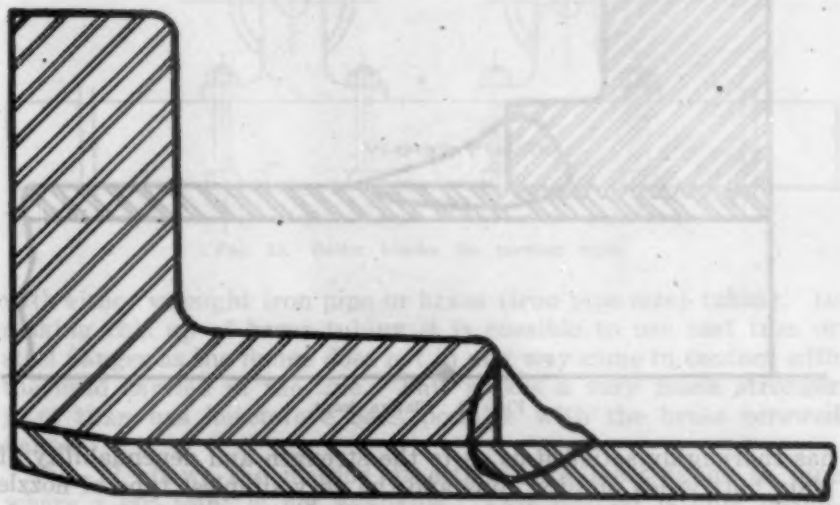


Fig. 11. Method of attaching flange to pipe where lap joint is not available.

1—MATERIALS

In papers previously submitted to this Society the selection of proper materials for oxy-acetylene welding has been quite fully discussed. We, therefore, will briefly rehearse only our own experience in order to have this matter clearly in mind.

Considering first the base materials we have found that where steel pipe is the best for the service required, open-hearth steel has given the best and most uniform results. There is less likelihood of tiny pinhole leaks as explained in former papers. In combination with this it has been our experience that nickel steel or other special rod having a strength greater than the base material give the strongest and most uniform welds.

For certain service lines in the power plant some engineers prefer genuine wrought iron pipe. This pipe can be very successfully welded. The filler rod for use in combination with this should be Norway iron or similar composition.

In many sections of the country brass piping is preferred for use on boiler feed lines and certain process piping. This piping can also be very satisfactorily welded. The filler rod for this is entirely dependent on the analysis of the base metal.

After the selection of materials comes their preparation for the actual job of welding. As before indicated, our own experience

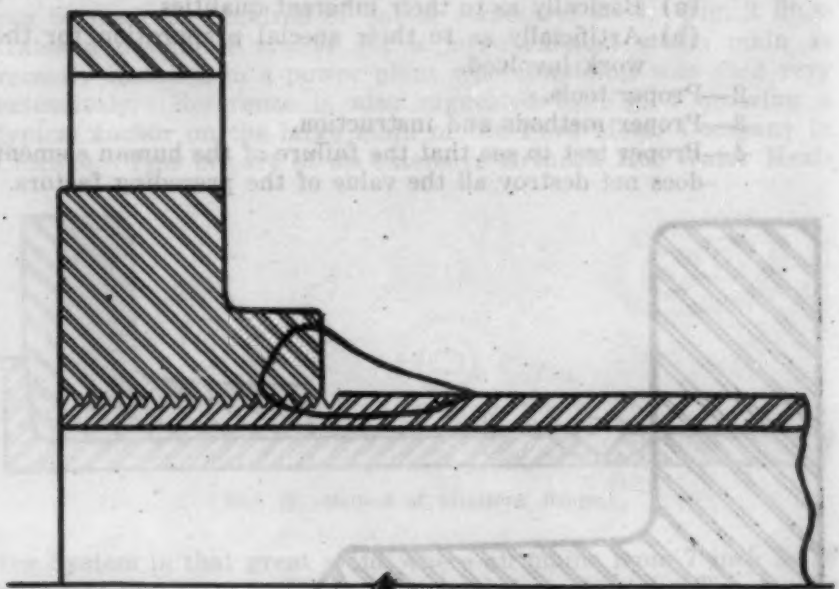


Fig. 12. Flange joint.

has thoroughly satisfied us as to the strength and dependability of plain butt welds on pipe runs and the very simplest type of nozzle weld. As a result, we have standardized on preparing materials as shown in the accompanying sketches Figs. 5 and 6.

An experience of nearly 15 years in welding has convinced us that careful preparation of materials in this manner insures a weld as strong as the base material itself, providing, of course, other factors later mentioned are just as carefully observed.

Figs. 7, 8 and 9 show some practical tests which a header containing one butt weld and two nozzle welds was given.

Photographs 8 and 9 show to what extent the pipe at the welds was distorted in an effort to show up any weakness. After being put to this severe treatment, the welds showed absolutely no fracture.

Fig. 10 shows the method of attaching a flange which we believe is the most satisfactory for this class of work regardless of

pressures. Where a flange is necessary at all it usually comes up against a piece of apparatus or valve and the lap joint flange allows a flexibility for connecting which is very desirable. These short lap joint pieces with their flanges can always be furnished in short lengths, with the end already machine chamfered to be welded into the line at any point. This is preferable to a welded flange for another reason. On the larger sizes particularly on account of the great amount of heat necessary to properly melt down the hub of a flange it is very difficult to keep the flange from warping. This means that it is not an easy task to make a tight flanged joint with an ordinary gasket. In our judgment there is little excuse for a welded flange as it has no advantages over the lap joint flange as the latter can be made fully as strong as the pipe itself. Very recently it has been found practical to also make this type of joint

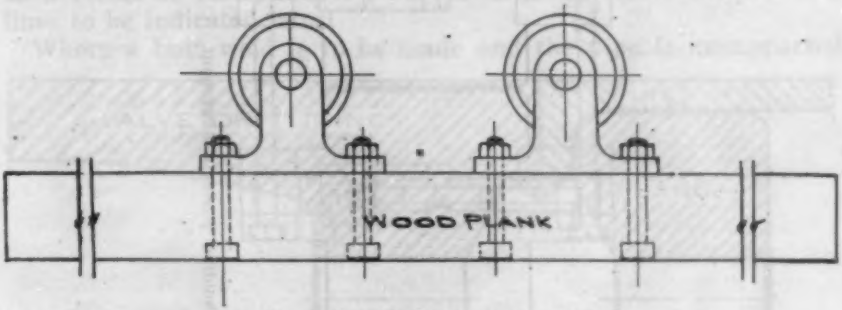


Fig. 13. Roller blocks for turning pipe.

with either wrought iron pipe or brass (iron pipe size) tubing. In making this up of brass tubing it is possible to use cast iron or steel flanges as the flange does not in any way come in contact with the fluid carried in the line. This makes a very much stronger joint than has heretofore been possible with the brass screwed flanges.

Fig. 11 shows the method of attaching a steel flange to pipe where a lap joint is not available. This method is only recommended for low pressures. Its only practical value is where large sizes of pipe are encountered. The flange can be machined as shown and a semi-lap joint made with an ordinary pene hammer and then a small fillet welded at the back to insure tightness and some additional strength. If preferred instead of pening the flange at the front a small welded fillet can be substituted.

Fig. 12 shows a type of flanged joint which will be found satisfactory where a welded flange is absolutely insisted upon. This should be a shop-made joint with a full cut taken clear across the face of the flange after the pipe is welded.

2—TOOLS

In discussing tools in welding work, we prefer to pass over as matters of individual preference such items as cutting and weld-

ing torches, etc., and to briefly describe certain accessories which have been found valuable in our work.

One very valuable accessory of this kind is a set of standard patterns which the welder can use in marking his cutouts on nozzle welds and on all special fittings. The invariable use of these patterns makes certain that the various sections will fit properly.

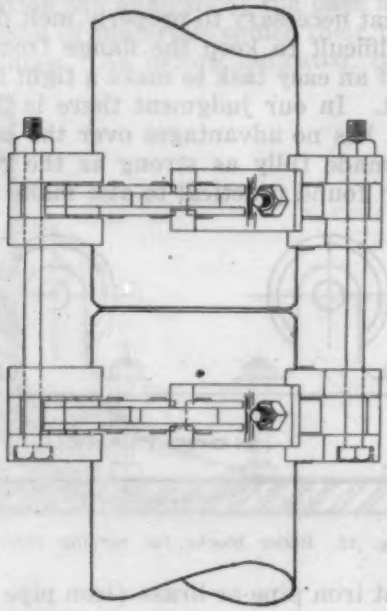
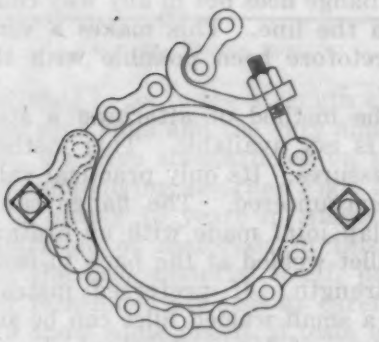


Fig. 14. Clamp for holding pipes in alignment.



They are time savers and in addition provide for uniformity which we believe cannot be secured by a hit or miss method.

Very little equipment is necessary as a rule in the construction of power piping work for holding the materials in position or for turning of the pipe. It is generally agreed that where practical it is best to turn the pipe so that very little welding need be done on the bottom. For the work which is done in the fabricating

shop little experience is needed to learn what is necessary in the way of tables and equipment so that the welders can work to best advantage. This is a matter which can safely be left to the shop foreman.

For work on the job as much of it as practical should be done on the floor. Where it is thought advisable simple roller blocks can be furnished for the pipe to rest in so that it can readily be turned. Sketch shown by Fig. 13 indicates a very simple method of making such an outfit with only plank and industrial truck rollers.

After the pipe is placed in the hangers and supports where it is to be permanently located it will usually be necessary to make an occasional joint where the welding will have to be done from the bottom. Apparently no special difficulty has been encountered as a result of this practice where the welder was trained along lines to be indicated later.

Where a butt weld is to be made and the pipe is unsupported

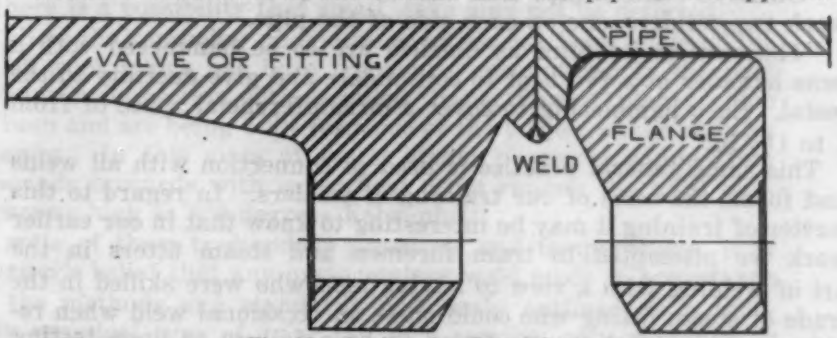


Fig. 15. Section of a Sargol joint.

for a considerable distance from the joint, it is sometimes advisable to use clamps to insure alignment. Sketch shown in Fig. 14 shows a range of several sizes of pipe.

3—METHODS AND INSTRUCTION

With proper materials, properly prepared and essential tools and accessories, we come to the very important matter of methods to be followed by the welder. These methods must be laid down by the Engineering Departments and welders must be instructed in following such methods to the last detail. If the method set up as a standard is not correct, the welder will never be a competent man no matter how conscientious he may be.

While there may be several excellent ways to do the same thing, we have found it best to choose one way and stick to it—so that constant practice may make perfect. For instance, our method of making a plain butt weld is made clear by the following copy of our instructions to foremen.

"Ends to be butted to within 1/16 in. of closed, then tack them together at two or more points. Commence the weld at a third

point and continue to weld around the whole circumference from starting point. It is important that when the welder comes to the point where he has tacked the two ends of the pipe together that this fillet be thoroughly remelted in tying into the new weld.

"Bring ends of pipe at bottom of groove to welding heat, puddle and weld ends of pipe before depositing any welding rod and bring both sides of groove to a welding heat as filling of the joint progresses.

"Fill the joint so the thickness of metal shall be one-third times greater than the thickness of the pipe: viz., pipe 3/8 in. thick, joint 1/2 in. thick.

"It is of extreme importance that in finishing the final tie-in weld that the weld already made be heated back on both sides for a distance of two or three inches.

"The joint shall extend beyond the edges of the groove; viz., width of groove 3/4 in., width of joint 1 in. to 1 1/8 in.

"On large sizes of pipe it is usually advisable and economical to work two welders, one on each side of the pipe.

"The sections of joint as finished are to be hammered with a pene hammer at a red heat to consolidate and give ductility to the metal. Each hammering to cover a circumferencial space of from 1 to 1 1/2 in."

This same general practice is used in connection with all welds and forms the basis of our training of welders. In regard to this matter of training it may be interesting to know that in our earlier work we attempted to train foremen and steam fitters in the art of welding with a view to having men who were skilled in the trade of steam fitting who could make an occasional weld when required. This practice was found to be a failure as upon testing the welds of such welders they were quite often found to be unreliable. It would seem that a man to make the very highest class welds must keep in practice continually just the same as in any other highly skilled art in which the hand plays a conspicuous part.

4—TESTS

In spite of an established method, careful training in that method and the development of a corps of men who do nothing but welding, our experience indicates that some check on welders must be constantly employed to keep them up to the standard. Our practice in this important matter is to take test pieces in the form of strips cut from the actual work at odd and unexpected times. These specimens may be tested either by bending to a hairpin shape or by pulling. In addition to these tests of routine work, we have also found it valuable where some unusual piece of welding in the field is to be done to give the selected welder special training in the shop where actual field conditions are duplicated as closely as possible. With such special training it is astonishing to see how exceedingly difficult field welding is done simply and easily.

While these periodical tests of the work of individual welders is an essential it is of course no guarantee of the quality and dependability of any large job such as a long welded line or header. Individual testing of this kind does, however, make it possible for fabricating concerns to test all finished work in a way that should establish its dependability.

It is now quite generally recognized that the most reliable test for welded work is what is called the "pressure and impact test." Each section of piping as it is completed should be tested with a hydrostatic pressure at least three times the working pressure in pounds per square inch. While holding this pressure the piping on either side of the weld for a distance of not less than three inches should be thoroughly hammered. This should be done around the entire circumference of the weld. Care should be taken in filling the pipe that a proper vent is placed in the line at a high point so that all of the air can be expelled. If care is not used in this there is a possibility that small leaks may not be detected.

In all of the foregoing no special mention has been made of the class of work which has been frequently encountered in the past few years in connection with so-called "Super-Power" plants which have been and are being built for some of the largest public utilities companies. In this class of work, steam pressures range from 350 pounds upwards with super heat often raising the total temperature as high as 800 degrees Fahrenheit.

In spite of these tremendous pressures and temperatures, it is the writer's belief that any oxy-acetylene weld made in accordance with the methods and standards previously outlined, is a thoroughly practical type of joint for such service. My reasons for this belief is that the weights of pipe used on such a surface provides a factor of safety which is a constant in that the temperatures involved have not yet reached a point high enough to weaken the resistance of the metals. Since welds, made the way we have indicated, are as strong as base materials, why should there be any doubt that a plain butt weld would be entirely sufficient for this high pressure, high temperature service? Reports of what some of the oil companies have done on a very large scale substantiate this belief since they have used plain butt welds in connection with oil piping where pressures and temperatures are as high and sometimes higher than are encountered often in these "Super-Power" stations.

In discussing this matter, we, of course, must have clearly in mind the tremendous responsibility that rests upon consulting engineers in designing these "Super-Power" stations. Often the comfort and convenience of a whole community may rest upon the normal functioning of these power plants, and it is only right and proper that they should have been extremely cautious in their designs to have provided a type of joint that was dependable beyond question. Certainly it is outside the province of these engineers

dealing with public utilities companies to undertake anything in the nature of an experiment. These engineers have, however, by their own specifications, indicated quite clearly that the all-welded line is a very desirable jointed method in this class of work by specifying quite generally what is known as the "Sargol Joint." This joint combines the strength of the ordinary flanged joint with the lasting tightness of the welded joint and frees the line from gasket trouble, which is a real problem where such temperatures and pressures are involved. Fig. 15 shows a section of a Sargol Joint. In this type of joint all of the fittings and valves are made of steel and are fitted with special flanges for welding. Specialties are also obtained with similar flanges. Naturally, the piping system of this type of joint is considerably more expensive than it would be with the all-welded equipment, but public utilities have been quite willing to bear that added expense until such time as they had entire confidence in the ability of welding concerns to produce uniformly a joint as strong as the base material. The one factor in this situation has been the matter of dependable workmanship which this paper has sought to stress wherever possible. The combination flanged and welded type of joint is a safety factor against poor workmanship in welding and its additional expense has been justified in many cases on that account and will continue to be justified until measures are taken which will go far toward guaranteeing the proper kind of welding procedure, including workmanship.

It is the writer's belief that autogenous welding of piping is at the parting of the ways. Either it is going forward very rapidly towards that ultimate goal its obvious advantages entitles it to reach, or it is going to be set back in its progress. Which way it goes depends upon what constructive means can be and are taken to establish it on some standard basis of uniformity. Because such a standard must provide for the very doubtful human factor in the individual welder himself or at least for a high degree of responsibility on the part of his employer, the problem is a complex one.

Simply as an effort to start some constructive movement and to encourage intensive thinking on this problem, which means so much to welding, the writer is bold enough to venture the following suggestion:

On May 19th of this year, at the A. S. M. E. Convention at Milwaukee, an informal conference was called by the A. S. M. E. Standardization Committee to consider the evidences of demand for a code on pressure piping. It was the general opinion that a code for this work has become a necessity. It was brought out that this was thoroughly indicated by the fact that the State of Ohio has already taken steps to start formulating a code which within a short time would be ready for legislative action. The opinion that seemed to meet with most popular favor at that con-

ference was that a committee should be appointed to formulate such a code and should work as a subcommittee under the A. S. M. E. Standardization Committee and the A. S. M. E. Boiler Code Committee. It was felt that if the A. S. M. E. should agree to formulate a code of pressure piping for national adoption that legislative action by the individual states could be temporarily forestalled.

I am bringing this out because at that conference the question of welding seemed to be one of the main points of contention and was thoroughly discussed pro and con. It is only a question of time until such a committee will become active and the legislatures will adopt their code just as the A. S. M. E. Boiler Code has been adopted in most states.

When that Code on Pressure Piping becomes a reality, welding will go forward or sink below its present level in proportion to the way that Code treats welding. In order that welding may be favorably handled in that Code, isn't it necessary that first of all this society develop a rigid specification covering welding? Shouldn't that specification not only cover materials, welding procedure, test of finished work, but also set up a definite plan of action looking toward rigid licensing of those manufacturers whose shop and field methods and whose integrity and responsibility are such as to warrant their being publicly recognized to do such important work?

High Strength Welds*

J. R. DAWSON†

Is a weld dependable? What is its strength? For years the answers to these two questions have occupied the attention of regulatory bodies, state authorities and others concerned with safety in industry. It has been the tendency of some of these bodies to base various regulations on the lowest strength welds that are made. This action emphasizes the need for welds of even higher strength than are now being produced. For the welding of structures that are to be subjected to heavy strains, the welding rods in common use could be called inferior because rods are now available that will produce welds of much greater strength than is obtained by the highest quality of workmanship with ordinary rods.

If the use of rods that will produce high strength welds became general, the procedure now followed in the manufacture of pressure vessels and in all welding where strength is of importance, might well be materially changed, and at the same time, when improved results were sufficiently demonstrated the codes and State

*To be presented at Fall Meeting A.W.S. in Boston, October, 1925.
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laws affecting such welding could be modified so as to remove some of the present limitations of welding.

Using pressure vessel welding as an illustration, it is recommended by leading welding engineers to use low strength plate because the welds now obtained have only about 50,000 lb. per square inch tensile strength. If welds of 60,000 lb. strength are secured, 60,000 lb. per square inch plate may be used and, without reduction of the factor of safety, the thickness of the material can be reduced by 20 per cent.

Inspection methods have been developed which insure to purchasers that the welding rods put out by the better companies are uniform in composition and quality. The inspection consists of careful sampling, chemical analysis, flame tests and investigation of welding quality of the rods. The welds obtained are subjected to bending and tensile tests, and other tests to determine the physical properties of the weld metal. All these precautions are expensive, but they are necessary if uniformly dependable quality is to be assured.

There are two types of commercially available rods that produce high strength welds and receive the careful inspection to which reference has been made. One of these is the nickel steel rod of S. A. E. Specification 2320, which contains about 3.50 per cent nickel. The other is a relatively new rod called "High Test" welding rod.

The nickel steel rod has been used for welding for a long time so that its welding properties are well known and a detailed description is not necessary. In the hands of a skilled operator remarkable results are obtained with it. The probable explanation of the fact that nickel steel rods are not more widely used is that some welders of ordinary ability have trouble with the occurrence of cracks in the weld while it cools.

Since the "High Test" welding rod is not widely known and the writer is familiar with the laboratory work carried out in connection with its development, a brief account of its outstanding features might be of some interest at this time. This rod is a steel of unusual composition and may be suitably applied in most instances of steel welding. The physical properties of welds made with it are uniform and similar to the best of the welds made with nickel steel rods. Since the so-called Norway iron and mild steel rods are the most largely used for welding steel, the properties of the new rod may be illustrated by a comparison with them.

Much more carbon is removed from the mild steel rod than from the Norway iron rod, so that the difference between the compositions of weld metal obtained is slight. The carbon is reduced by combination with oxygen and the carbon monoxide or carbon dioxide formed are the cause of blowholes that may be included in the metal. By this removal of carbon the most valuable strength-

ening element of the steel is lost. It is generally conceded that most welders have greater success with the very low carbon rod and the explanation is that when the mild steel rod is used the tendency is toward greater evolution of gases and the production of spongy metal.

TABLE 1

Composition of Welding Rods

	Norway Iron Rod	Mild Steel Rod	"High Test Rod"
Per Cent Carbon	0.05	0.25	0.20
Per Cent Manganese	0.15	0.45	0.80
Per Cent Silicon	0.01	0.02	0.55

Composition of Weld Metal Obtained From

	Norway Iron Rod	Mild Steel Rod	"High Test Rod"
Per Cent Carbon	0.03	0.08	0.18
Per Cent Manganese	0.07	0.20	0.48
Per Cent Silicon	0.01	0.01	0.25

The new rod, of which a typical composition is included in Table 1, provides means for overcoming the undesirable defects referred to. The virtues of this steel are imparted by the manganese and silicon, particularly the silicon. When this rod is used for welding, both manganese and silicon are oxidized at the same time. Silicon is inherently more easily oxidized, but the manganese is also oxidized because it is present in greater amount. The oxides formed, together with some iron oxide, combine to form an iron-manganese silicate that readily floats to the surface in the form of a slag, which although extremely shallow, protects the molten and cooling metal from the oxidizing action of the surrounding atmosphere, and thus keeps the amount of oxidation at a minimum. Furthermore, the presence of these amounts of manganese and silicon provides a means for the prevention of the formation of carbon monoxide and carbon dioxide gases. Their greater affinity for oxygen, either as such or in the form of oxides, prevents the union of oxygen with carbon during the deposition of the weld metal.

It is found that the best welding properties of this new rod are developed by an approximate percentage ratio of 3 manganese to 2 silicon. Under these conditions the metal being deposited flows well but is not so fluid as to be difficult to control, and the slag formed contains such proportions of the oxides of silicon, manganese, and iron that it fuses easily and floats readily to the surface of the molten metal. These conditions are ideal for the obtaining of a weld metal that is cleansed by the deoxidizing action of the manganese and silicon contained in the rod, and protected from oxidation by the covering slag.

Rods which are coated with a thin layer or more heavily covered with a fluxing material, supply a slag that during welding acts as a protection to the molten and red hot metal. The new welding rod differs from such flux-covered rods and is an improvement in the following respects:

1. The elements which have the fluxing action are a part of the welding metal and not merely a surface covering, thus providing a cleansing agent throughout the metal being deposited, so that wherever oxidation may occur the active deoxidizers are immediately available to remove the impurity in the form of a suitable slag.

2. The slag covering on the weld from the more heavily coated rods is usually so excessive as to impede the welding operation, while that formed during welding with the new rod is a very shallow covering that offers just as efficient protection to the metal without the objectionable heavy coating of slag.

3. The constitution of this new rod is such that both a deoxidizer and a flux are provided for the protection of the deposited weld metal, while the coated rods supply only a flux which is available to act as such at the surface, thus being without effect for the removal of oxides contained beneath the surface of the metal.

4. The thin coating of slag on the "High Test" rod makes the control of the molten metal easier.

5. This new rod is also much more efficient in preventing the removal of carbon during welding than is the case with the covered and coated rods.

The practical advantages of the new welding rod may be illustrated by further comparison of its properties with those of the commonly used Norway iron rod. The important advantages are:

1. The welds obtained are of superior physical properties.
2. The rod is more "fool-proof."
3. The metal is deposited at greater speed.
4. The weld obtained is less expensive.

A good welder obtains about 20 per cent higher tensile strength, or an increase from 50,000 to about 60,000 lb. per square inch. A beginner at welding obtains an even higher percentage increase of tensile strength; for example, 35,000 lb. per square inch for Norway iron, and 45,000 lb. per square inch for the new rod. These values are averages obtained in tests of the work of a great many welders.

Comparative cold bend tests made with a machine that forces the bend to occur in and close to the weld, show that weld metal from Norway iron rods will bend through about 20 per cent greater angle without cracking, but the weld obtained with the new rod is 50 per cent more resistant to bending. When welds with this rod are made in low carbon steel plate and the welded specimen clamped in a vise and hammered, it is practically impossible to cause bending to occur in the weld on account of the strength and stiffness of the weld metal. The material of the plates is weaker and more ductile and naturally the deformation occurs outside the weld.

The use of this welding rod should be of great value for welding articles that are subjected to alternating stresses as would be illustrated by the breathing action of pressure vessels or the vibration

to which welded pipes are frequently subjected. Increase of tensile strength adds to the endurance properties of metals and gives them greater resistance to failure by alternating stresses.

Tests have shown that welds with the new rod are of better quality than Norway iron welds when subjected to the hot bend test. Because Norway iron rods approach so nearly to pure iron, more of the oxidation that occurs consists in the formation of iron oxide. At the temperatures attained appreciable amounts of iron oxide are dissolved in the weld metal, and as a result there is some tendency to red shortness. The strong deoxidizing elements contained in the new rod prevent the solution of iron oxide and practically eliminate the danger of red shortness. This property will make the rod especially suitable for boiler welding, for in addition to freedom from red shortness, the greater strength and resistance to cold bending and improved endurance properties all combine to make boiler welding even more dependable than it has been in the past.

Table 2 is included to illustrate average values in a series of tests of welds made with various rods.

TABLE 2

*Tests of Welds**

Tensile Tests

Welding Rod	No. of Tests	Yield Point	Average Tensile Strength	Average Elongation (2 In.)
Norway iron	5	38,500	51,600	10.2
Mild steel	5	39,000	50,300	8.4
"High test rod"	12	42,800	62,400	11.2

Cold Bend Tests				*Hot Bend Tests*	
Rod	No. of Tests	Load, Lbs. Per Sq. In.	Angle of Bend	First Crack Angle Bend	When Bent Flat
Norway iron	8	9,500	63	135 deg.	Slight crack
Mild steel	5	10,850	28	100 deg.	Slight crack
"High test rod"	6	15,400	54	150 deg.	Very slight crack

*All welds in ½-in. thick plate with weld and plate machined to same thickness.

Welds for tensile tests made in ship plate, having tensile strength of 58,000 to 68,000 lb. per square inch.

Cold bend tests with machine, and according to method recommended in Bulletin No. 1 of the American Welding Society.

For hot bend tests, specimen clamped in vise, heated bright red and bent at weld by hammering.*

That this rod is more "fool proof" has been demonstrated by the work of a great number of welders, all of whom, without exception, have obtained better test results with this than with other rods. These welders have been of varying ability; some were expert, some of ordinary skill and some relatively inexperienced. The consistent improvement in weld quality that results from using the rod is due to the high manganese—high silicon combination, which prevents the elimination of appreciable amounts of carbon, makes the

weld metal better able to withstand improper treatment during the welding, such as overheating and produces a slag easily distinguished from the metal when they are molten. When welds are made with Norway iron, iron oxide covers the weld. The melting temperature of the oxide is less than that of iron, and welders often mistakenly believe the metal is being melted when it is really only the oxide covering that flows over the surfaces to be united and causes the inclusion of oxide films, laps, and poor fusion in the weld.

An outstanding advantage of the new rod is increase in speed of deposition, which in a large number of tests has ranged from 17 to 45 per cent. The increase of speed is more pronounced in welding heavy material. The very rapid welding is due to the great ease of flowing together of the metal and to its suitability for withstanding high temperatures. It is frequent practice to use a size larger welding head for this rod than is proper for Norway iron.

The cost of welding is also materially lowered by using the new rod. There is a saving in the welding time when the same size welding flame is used, and with a larger flame the time and amount of welding gases is still further cut down, for a definite amount of heat is required to melt a given amount of metal, and the more slowly the welding progresses the greater the quantity of heat that must be supplied to compensate for radiation and conduction losses. There is a saving even in the weight of rod required, since no sparks are produced during welding, and many are thrown off when most rods are used. Each spark is a small globule of burning metal and this combined with a certain amount of metal that is vaporized constitutes a loss of weight of several per cent in the passing of ordinary rods into the weld.

As a result of extensive laboratory investigations of welds made with the new steel and of about three years' use in commercial welding, the following statement is confidently made:

The rod will serve the needs of the industry by providing a means of obtaining better quality welds at less cost, by making the process less dependent upon the skill of the operator and by widening the range and dependability of the oxy-acetylene process.

The writer desires to acknowledge the helpful assistance given by his associates in the investigation that has led to the production of this new rod and to state that credit is due F. M. Becket for the origination of the idea upon which its composition is based. The work serves to illustrate the improvements that may be accomplished when expert metallurgical training and skill are applied to welding problems.

Control of Manufacture and Acceptance Tests of Welding Rods*

H. M. CARTER†

There are several major considerations entering into the execution of any welding operation. The choice of welding operator and the selection of suitable parent metal to be joined, when this is possible, are of course of utmost importance and cannot be lightly stressed. The third factor, which is just as important as either of the two mentioned, is the selection of suitable welding rod.

In the past too little consideration has been given to the choice of welding rod, with the result that in at least some cases of failure of welded joints, analysis has failed to show tangible cause for such failure, the only misjudgment having been in the use of material of very ordinary quality for welding rod. Unfortunately, too few welding operators and even too few managers of large concerns, realize the importance justified in the choice of filling material. It has been commonly supposed, in the past, that for ordinary work the welding rod was of little importance and that for the most exacting operations, the welding rod needed only to be of approximately the same composition as the metal to be joined, in order to produce satisfactory joints. However, practice has since shown that this is far from true, and it will be found in the best present day practice that the composition of the most satisfactory welding rods may vary considerably from the composition of the parent metal.

Welding rod material, until a few years ago, was purchased from the steel mill entirely to specifications of chemical composition.

However, it has since been found that the chemical composition is only a small part of the story, and it is perfectly possible to have a welding rod that will analyze within satisfactory chemical specifications and still will be entirely unsatisfactory for use in welding operations. It has been found that control very much closer than required for the usual manufacture of metals is necessary.

In concurrence with present practices of specialization, it has been realized that metal manufacturers are in the best position to manufacture the metals. However, since the uses of metals in welding rods are so special, close cooperation between Oxy-Acetylene apparatus manufacturers and the metal manufacturers has been necessary in the development of suitable welding rod material. This has resulted in the manufacture of welding rods to very rigid specifications, set up by the apparatus manufacturer. Each and every lot of rod supplied against the specification is very carefully inspected and checked, to determine whether the material is suitable for use in welding operations.

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†Oxweld Acetylene Co.

The present complete specification for the manufacture of welding rod embodies requirements covering method of manufacture, character of finish, specification of limiting chemical composition, physical properties of the material itself, physical properties of welds actually produced with the welding material and special requirements peculiar to the welding rod metal. Of course, the usual dimensional specifications are included in the specification.

Since the usual methods of manufacturing are acceptable for most rods, considerable leeway is given the manufacturer in his selection of the process to be used. It has been necessary to impose only a few limitations. In some cases it is necessary that the rod shall be cold drawn rather than worked hot, in order to obtain a surface free from oxide inclusions, and in certain instances the specification of suitable grade of raw materials is required.

The requirements for finish, cover principally specifications for elimination of foreign matter and the use of dips or baths in the manufacture which may cause subsequent chemical action on the surface.

The chemical specification for each type of welding rod covers completely the manufacturing limits for all necessary constituents and the maximum permissible content of undesirable elements.

Compliance with the chemical specification is closely checked by the usual methods on samples taken from various parts of the lot which are machined and thoroughly mixed. In case of any disagreement in chemical determinations, check analyses are run.

The physical properties of the welding rod material itself are unimportant except as a measure of the quality of the material, since the original physical properties are altered in the welding operation. The specification for physical qualities of the rod cover bending tests to determine the ductility and character of the metal as a measure of its quality.

The specification for the suitability of the material for welding operations embodies the actual production of welded joints under welding shop conditions. In order to prove the material in this respect, a plate of suitable dimensions is welded and later cut up into three coupons conforming to the test standard of the American Society for Testing Materials. These coupons are then tested for tensile strength and must show a strength greater than the specified minimum. In welding the test plate, the two parts are placed parallel with edges close together along the line of welding, and tack welded at the far end with respect to the direction of welding. The weld is then executed. Since the two parts have been held rigid throughout the welding, the greatest possible strain results in the finished joints. The required plate material, thickness of plate, type of welding apparatus, size of flame and gas pressure are specified for each type and size of welding rod.

When these welding tests were first found necessary, the metal manufacturers were not at all readily convinced that such tests

were fair, claiming that too much depended on the skill and day-to-day variation of the welding operator. In order to overcome this resistance, very careful records were kept of a great number of tests conducted under variable shop conditions, with a number of different operators. These records showed that the quality of the rod itself could be very closely checked by the welding tests.

The specifications referred to above as special require that the welding rods shall be free from inclusions of foreign matter, metal, slag and dirt, and that the rods when melted, shall flow freely and smoothly. These special requirements are tested by melting representative sample rods taken from each heat of every size. Experience has shown that variation sometimes occurs even in a small lot of rod and therefore it is necessary to select a much greater number of samples than would usually be taken for inspection purposes making sure that the samples represent every part of the lot. Even in very large heats as much as one sample for every two hundred and fifty pounds will be tested.

It should not be thought that testing for these special qualities is a simple operation. On the other hand it is most exacting and only an observer of broad experience in welding and with very thorough special training can be relied upon to pick out the qualities sought. The so-called flame test is most interesting to the user of welding rod since it is the only method by which qualities most essential in the rod can be controlled.

The flame tests have been found so necessary that most welding rods are thus tested at the metal-manufacturer's mill before shipment is made, forming the primary basis for acceptance or rejection. The tests are of great help to the manufacturer as a control method, for, the metal in semi-finished state can be flame tested at certain stages during manufacture eliminating the possibility of carrying through to finished state metal which would later be found unsatisfactory, but a good deal of time was necessary in training the metal manufacturers' observers to qualify them to use the flame test for control. The value of these tests in advancing welding rod manufacture is shown by the record of rejections of material since the adoption of the tests. In the case of one manufacturer, in a period of two years, the rejections were reduced from 28 per cent to 4 per cent of all material offered.

The importance of the choice of suitable welding rod cannot be over-estimated and it is hoped that the foregoing outline of the methods necessary in controlling good quality welding rod may bring about a greater realization of the importance of this factor.

Welding Wire a Factor in Good Welding*

C. A. McCune†

Welding Wire for both gas and electric welding continues to maintain prominence in the art, and thanks to the American Welding Society and other technical and engineering associations, it is today well protected, as never before, by specifications particularly regarding the chemical properties.

In all cases, however, under the specifications the actual welding qualities are left to the discretion of the manufacturers and jobbers of wire and no check tests other than the actual welding operation are provided.

The value of the weldability test depends on the qualifications of the welder and wires that may be considered as operating fairly well do not always disclose any contained variations from the specifications such as the presence of impurities and inclusions, with the result that there is a possibility of these detrimental elements if present being introduced into the weld deposit.

The expert welder will readily recognize this operating condition and if allowed will provide against using wire of inferior quality. Circumstances, however, do not always permit tests by experts and in many cases the expert is not favored with the authority to reject other than the highest grade wire due to the fact that his superior is much concerned in the cost of wire or is under the impression that welding wire (providing the chemical analysis is within the specifications) is the ordinary run of mill wire masquerading under the more dignified title of welding wire. Unfortunately this version is warranted in some cases by a sad past experience.

Then, again, the issue is sometimes raised that certain welding work is not important, i.e., the work is not required to withstand any particular load or strains and therefore quite ordinary wire is considered satisfactory. This attitude is, however, more representative of those who have adopted welding in a more recent period and is not held by those of longer experience.

Fundamentally all welds are important, but if a distinction is to be made in the results expected, it is not economical from a welding speed standpoint nor is it safe practice to have both good and ordinary wire in the same plant. There are no doubt many who could testify that it is wrong to consider such practice safe simply because it has not given trouble so far. The wire should all be of good quality and rapid simplified test methods will assist in readily determining whether it is or not.

The object of this paper, however, is to draw attention to the fact that provisions are possible for a more rigid specification for the further protection of welding wire as well as an appeal to the

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†Director of Research, American Chain Co.

consumer to refrain from considering wire of the "market" type in preference to wire particularly processed for welding. The value received is that paid for and the results will be in proportion.

If "market" type wire (which never should be classed with welding wire) is used, there will not be much difficulty in determining the cause when failures occur.

There have been several valuable papers contributed on welding wire in the last few years in which are embodied practical and laboratory methods for testing the wire other than by the actual welding operation. These findings are the result of careful study and some of these test methods are practiced by large users who know of them. They would undoubtedly be used generally if better known.

These tests have been gathered together and are suggested as additions to the present AWS specifications and to be a part of them and they are of such a nature as not to inflict any manufacturing hardships.

The test methods which follow are suggested as offering to the practical man as well as to the chemist and metallurgist further means of determining the qualities of the wire.

Flame Test

This test is made by laying the wire flat on a clean surface and applying a standard oxy-acetylene welding flame to it in such a manner as to heat it up for a distance of about 6 in. plying the flame back and forth until the wire is red and then slowly melting it, moving the flame steadily forward so that the wire melts only half way through its diameter. (This avoids taking up any substance foreign to the wire itself.) It is necessary, however, to melt half way through as melting the surface only is not sufficient for observation. The smallest tip available should be used, care being taken to produce a neutral flame.

If the flame is withdrawn as soon as the metal begins to melt, the impurities if present can readily be seen being thrown off in the form of sparks, or a boiling action will occur in the case of inferior material indicating undesirable elements such as gases and slag, and in some cases the metal will not flow together but tend to "run away." On cooling, the metal will present a spongy appearance (Fig. 1, A to F). In the case of clean metal practically free from impurities, the wire will melt and flow together evenly without displaying any disturbing action (Fig. 1G).

This test applies to both gas welding rods and electrodes. It does not, however, indicate the actual welding characteristics of an electrode, but will give sufficient evidence of what may be expected in a weld deposit from such metal, notwithstanding the fact that the electrode may, in a good many instances, pass operating and other physical tests.

Electric Current Test

The melting test may also be conducted with electric welding apparatus by "freezing" one end of the electrode to the work or

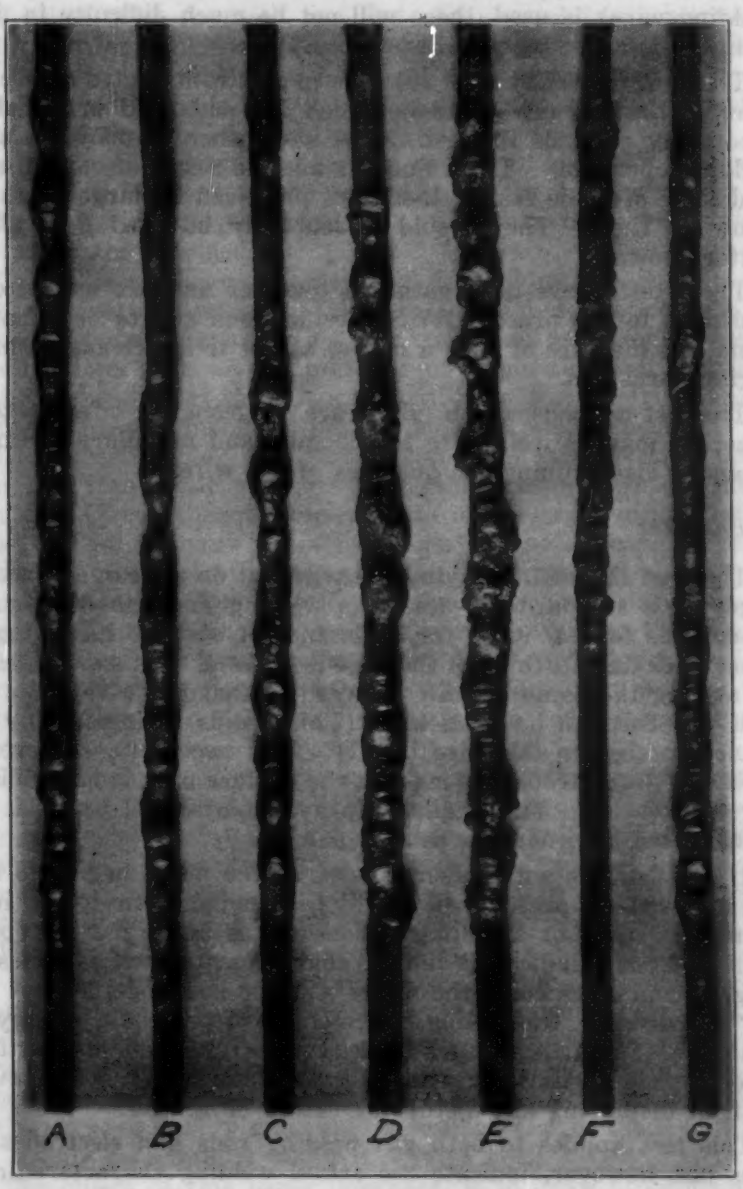

Fig. 1. Results of Flame Test.

plate, using the normal welding current for the size of the wire involved. By keeping the wire in direct contact with the plate it

will reach a uniform melting condition, but if the current is too high the wire will melt close to the plate only and not present sufficient melted surface for observation. It is, therefore, necessary to adjust the current so that the wire heats up slowly throughout its entire length.

The microscope may be used to advantage for several determinations, such as the presence of dirt or slag (Fig. 2) and the general characteristics of the structure of the wire (Fig. 3 and Fig. 4). It has been found that a well-rounded grain structure is more favorable to the flowing properties of gas welding rods. For electrodes

MICROSCOPIC EXAMINATION

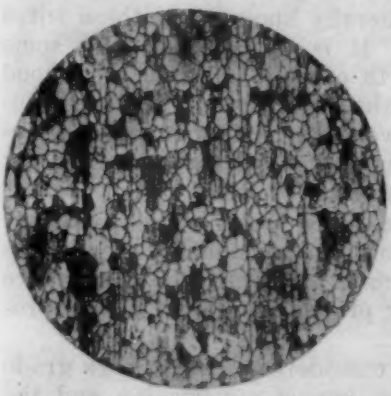

Fig. 3.
Typical Grain Structure of Satisfactory Oxy-Acetylene Welding Rods.

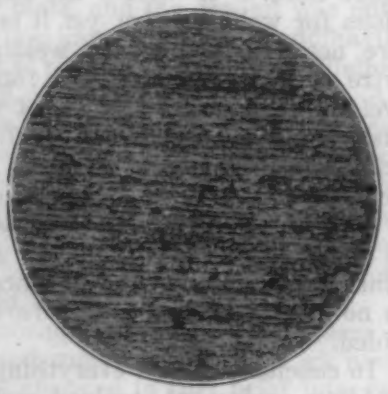

Fig. 4.
Typical Grain Structure of Satisfactory Electrodes.

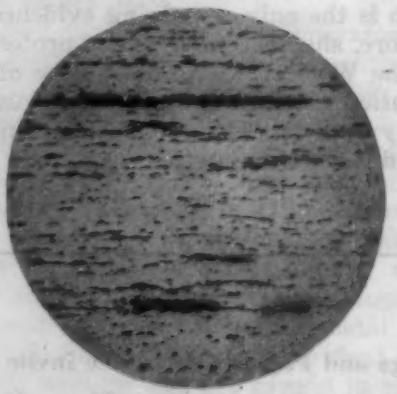

Fig. 2.
Photomicrograph of Wire containing Slag.

the most satisfactory results have been obtained by the author from wire having an elongated grain structure.

As an illustration that chemical analysis alone does not guarantee a wire to possess all the necessary requirements for welding,

the few following wires taken at random from the type commonly termed "market" products are offered for consideration:

Name	Chemical Properties Carbon	Manganese
Bailing wire	.08 — .20	.20 — .50
Market wire	.08 — .20	.20 — .30
Fence wire (common)	.08 — .12	.30 — .50
Strand wire (common)	.08 — .12	.30 — .50
Rivet wire	.08 — .15	.30 — .45
Nail wire	.08 — .12	.30 — .50

These wires as finished have varying physical properties but meet fully the requirement for the purpose intended. They all come close to or within the chemical range allowed by specifications for welding wire, yet it is generally known that these wires are not satisfactory for welding. It is true occasionally some wire of this class has been found to exhibit fair and even good welding qualities, but it is not within consideration of being consistently fair or good. Wire for welding, besides being of carefully selected chemical analysis, requires definite special processing separate and distinct from any other class of wire.

The situation before the existence of welding wire specifications is common knowledge and the general improvement in conditions since the adoption of the specifications is also well known, but there is no good reason why still further protection should not be provided.

In conclusion when everything is considered, such as high grade welding equipment, trained welders, expert supervision and the material to be welded (which itself is usually surrounded by the most rigid specifications) it is only fitting that the little piece of melted wire which is the only remaining evidence of all the effort that has gone before, should receive every protection possible and it is hoped that the Welding Wire Committee of the Society will give due consideration to these and other suggestions that may be offered where they apply to low carbon iron and steel wires for bare electrodes and gas welding wire.

The Meetings and Papers Committee invite discussion of the papers presented in this issue. These discussions may be presented at the Fall Meeting or sent in to the Editor for publication in the next issue of the Journal.

Metallic Arc Weldability of Ferrous Metals*

C. J. HOLSLAG†

The first metallic arc welding in this country, at least on a commercial scale, was done by Siemund in New York and Schuler in Boston in 1908, who brought this process from Germany, and a 5/32-in. bare pure iron wire was used with approximately 150 amp. direct current; in each case from a steam-driven shunt generator varying from 110-90 volts; regulation being through a series resistance in the form of a salt water barrel. The welding deposit was made on steel, generally boiler plate, and the deposit was pure iron from a pure iron rod, at that time imported from Scandinavia. When using a bare wire the deposit is pure iron, no matter whether the rod at the start is a mild steel or medium high carbon. Although this deposit on steel or iron is pure iron, it is an apparent stranger to metallurgists, and while one eminent authority referred to it in the early days as diseased steel, yet at the present time the consensus of research opinion appears to be that impurities and compounds not associated in steel of furnace origin mix with and separate the grains of this arc deposited metal, making it cold short or brittle-like, to use accepted terms.

The electrode, or melt rod, in passing through the arc where it melts, vaporizes, perhaps gasifies and condenses on the work piece again as metal has become entirely changed in that brief interval. It has been passed through an electric furnace at a very high temperature and one that is not inclosed or even slag protected unless flux-cooled electrodes are used.

It is a well-known fact that high temperatures are invariably favorable to a chemical reaction. Consequently the temperature generated by the electric arc, which will melt refractory metals with ease in an instant, and is the highest temperature that can be produced, would naturally greatly encourage any tendency toward a chemical reaction. The first reaction is the universal chemical reaction—oxidation, and it will occur readily if the melting process takes place in air or anywhere in the presence of oxygen. In addition to oxidation, compounds of nitrogen and iron and nitrogen and carbon are formed which, together with impurities in the air, melt rod and the parent metal forms compounds and mixtures which do not have time to float to the surface in ordinary bare wire welding and are caught in between the grains and produce the brittle weld.

The chief problem is, primarily, to shield the molten metal as far as possible from contact with the air, and then to dispose of whatever oxides or nitrides have unavoidably formed. If the

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†Chief engineer, Electric Arc Cutting and Welding Co.

proper fluxes are chosen, both these conditions may be thoroughly realized. If it is possible to surround the active weld with an inert mass that will melt at the temperature of the arc but will not combine with the air, the molten metal will then be prevented from coming in contact with the air, and oxidation will be greatly re duced. This is actually the condition realized in the use of the slag-coated electrode. This special electrode has a coating of such thickness and quantity as to melt at a steady rate with the melting of the electrode tip, and to form an envelope at all times about the arc and the molten puddle. A coating such as this may be of slag, asbestos or various silicates, in short, any material that may be used as a coating and will not combine with oxygen. The drawback to this type of coating is that the slag is liable to become entrapped in the weld and in protecting the deposit from microscopic impurities actual deposits of slag may be found in the weld.

Besides this type of inert coating, the electrode may be coated with fluxes which are chemically active in a favorable way. These are valuable in other duties besides the all-important prevention of oxides and oxidation and they may be chosen to combine with and eliminate various undesirable elements in the welded metal itself or they may be effective in producing any desirable chemical composition in the deposited metal, or they may, as in soldering, act to clean the welding surfaces from dirt, grease or oxide. All these actions are, of course, favored by the heat of the arc, and may be combined in one coating of flux. It is well known, when welding with bare wire of any ferrous composition whatever, that the resultant weld is composed of pure iron, because the high temperature of the arc drives off the other ingredients as gases. It is the function of the flux to prevent this state of affairs, and it does prevent it in a most effective way. As a matter of fact, modern developments in flux coatings have made it possible to lay down deposited metal of a predetermined composition, so that it is now possible to duplicate in the weld such metals as manganese steel, high-carbon steel, and other steels of very special qualities impossible to deposit with the bare wire electrode, no matter what its composition.

The tensile strength with bare wire is equal or better than the best mild steel or boiler plate but the ductility and resistance to alternating stress is far below the sheet, plate or forged steel or iron. One would hope that because the weld deposit is pure iron that ordinary iron could be welded by the arc and all properties realized. This unfortunately is not so, however, not only because of factors mentioned in the previous paragraphs but because the arc deposit is a casting, while the parent metal has been puddled, forged, rolled or a combination of these processes which has squeezed out the impurities and amalgamated and refined the metal far beyond its casting stage.

This casting phase of an unforged weld deposit is often momen-

tarily lost sight of but the least reflection will show that it is most often impracticable except in research practice to forge an arc weld. We have all read specifications for welding where alternate hammer blows and weld deposit must be made and we do know that light bobbing or caulking with an air gun improves the surface and allows the interior to sort of adjust itself, especially if the jarring action is done while welding.

There is no pure iron or mild steel that cannot be arc welded but the easiest ferrous metal is mild steel of .06 to .16 carbon range and the best electrode to use is one with approximately the same carbon content, even although with bare wire practice a pure iron deposit is made. It seems that with a moderate amount of carbon, say up to .20-.25 the burning out of the carbon purifies the weld deposit but much carbon above this amount makes the weld like gingerbread although stronger up to about .65 carbon. Of course with coated electrodes almost any desired deposit of carbon content can be realized, but even with coated electrodes a considerable percentage of extra carbon must be provided in the filler rod.

Nickel alloyed with steel helps considerably to prevent the boiling or burning out of the carbon, and nickel does not appear to be appreciably affected by the temperature of the arc and a reasonable amount of nickel can be deposited without loss. Nickel alloy steel deposits have one disadvantage and that is incipient hair line cracks on the surface. They are harmless but do not appear so and it has been found that chromium alloyed with nickel prevents this surface action. The fact follows that nickel and chrome nickel alloy steels can be welded nicely even with a non-alloy bare electrode. The nickel and chrome alloys referred to are the ordinary automotive steels of say 3½% nickel and up to 1½% chrome or combinations. With these steel alloys as a welding rod greatly increased tensile strength of the weld deposit is obtainable. The chrome nickel alloys, where the percentage is high, say 30-40% and over, are practically unweldable in the present state of the arc process except by the use of flux coated electrodes and by the use of these electrodes practically perfect welding can be attained on all the compounds of nickel with copper, chromium, silver, manganese, etc., which without such flux coating welding is practically impossible. An exception is monel metal which is an alloy of nickel and copper used exactly as found in mining nickel and this alloy welds very well even in sheets. In other words, the composition of monel plate is a natural result of reducing the ore and is useful "as is." It must be chromium that is the offender because pure nickel welds nicely and any compound of nickel and copper or nickel and iron, or nickel and manganese, each with or without iron, can be arc welded. In fact, nickel wire and high nickel alloys such as monel wire are used extensively in the welding of cast iron without preheating where a machinable deposit is desired. This property of a high nickel electrode is the most wonderful develop-

ment of the art because not only is the deposit soft but there is no hardened layer of cementite in or near the weld and nickel appears to hold the graphite in the cast iron from going into solution and forming the hardened weaker layer of "white" cast iron. Cast iron is easily welded with an ordinary steel electrode but the contracting strains are very liable to pull the weld loose at this weakened layer and studding or some other mechanical dodge must be employed to keep the stretch in steel weld where it can be taken care of without fracture. Fluxed electrodes are a great aid in welding cast iron and practically all other ferrous alloys.

Manganese up to .65-.75% with medium carbon content is a very useful welding electrode and by an action similar to the cleansing of the deposit by medium carbon alone gives greatly improved tensile strength, not as high as the nickel alloy but so that 65,000 lb. to the square inch welds in boiler plate can often be obtained. Manganese in its engineering content of 10 to 15%, however, is more liable to boil the deposit into a gingerbread mass than make a good weld. Manganese in this respect acts like high chrome or chrome nickel alloys but not quite so badly. Depositing high manganese can be done easily with the fluxed or slag-coated electrode and the desired content can be realized in this manner. Of course, many manganese steels realize their desired properties from heat treatment and the weld deposit must be likewise treated to duplicate the original metal properties. Manganese steel is generally cast, and the cast weld fits in admirably except where it is impractical to duplicate the heat treatment. In this case it would appear better to use our old friend the nickel or nickel chrome alloys of steel, as they are self-air hardening and by employing the correct carbon content in the flux coating can be made as hard as desired.

Vanadium steel fortunately contains very little of that impurity, as it escapes readily at the temperature of the arc, but as common alloys are .02 per cent, this is not serious and this alloy is nicely welded. Also vanadium steel rods give a greater tensile strength, something between that increase caused by manganese and nickel chrome steels, but their use in a commercial extended manner has not as yet become universal. It is a strange unexplained fact why vanadium, manganese and carbon increase the strength of the weld deposit while they are absent therefrom. Vanadium is the strongest of these elements, because although not even a trace can be detected in the weld deposit assay, yet a noticeable increase in the strength is discernible with even .01% of this element in the electrode.

Silicon steel is not often called upon to be welded because of the character of its commercial use but silicon in steel in the ordinary amounts does not cause any disturbance in the welding; in fact, as an impurity in the electrode it is desirable from its ability to cleanse by collecting and floating dross and slag to the surface. In fact, silicon is the basis of practically every slag coating and it has

a quieting action in addition which is very valuable. In commercial steels its content does not run high but if such an alloy were made, it would probably boil as does manganese and chromium.

Aluminum and magnesium steels are nicely welded; in fact, both aluminum and magnesium are used in the flux coating of welding rods to help along the fluxing action. Aluminum and magnesium alloys in which their content is preponderant have not as yet been commercially welded by the arc process.

Tungsten and molybdenum alloys of steel are also in the unsolved class unless the content is very low, as with vanadium.

The arc temperature appears to be too high also for tin and lead, although the latter is very nicely welded by the contact or semi-arc process and easily, neatly and cheaply cut or burned by the same method. This semi-arc process is also very useful in depositing nickel, either pure or manganese alloys or monel metal in cast iron for satisfactory welding of defects in cast iron. The arc in this process is as its name implies, a contact or semi-arc and the resultant deposit, except in the case of lead burning, is intermittent but easily connected into a homogeneous mass by skilful manipulation.

Cast iron, the most commercially used of the ferrous metals, is weldable cold under almost any condition, due to recent developments in the art, and of course if preheated, the weld can be made with a cast iron or steel filler rod in a manner similar to gas welding. The development and future of the arc process has been along the lines of welding without preheating and much satisfactory progress has been made.

If a filler metal of different composition than that of the parent metal is to be deposited, the difference between the rates of shrinkage of the two must be taken into account. For, if the parent metal shrinks faster than the metal of the weld, the two are apt to become separated, so that one slides over the other, and the purpose of the weld is thus destroyed. Or, if the weld itself does hold, the brittle cast iron about the weld is likely to crack as a result of the internal strains that have been set up. This may be prevented by proper preheating, by the use of certain kinds of electrodes, by adding a chemical flux which will tend to keep the weld free of hard carbon compounds, or by proper studding.

The operator must be prepared to meet the following characteristics in the average cast iron welding job; lack of tensile strength, and average content of carbon of about 3½ per cent which will tend to harden the weld under heat, large coefficient of expansion, and tendency to form the products of oxidation (slag and dross). All these properties, chemical and physical, must be overcome before a successful weld can be made, and hence they are of great importance to the operator. He may easily take steps to overcome these difficulties, however, if he thoroughly understands their causes.

Malleable iron welds nicely with the arc. The properties of

deposit of a mild steel electrode very closely resembles good malleable iron and none of the malleable properties are lost if too much heat is not used; in other words, if the parent metal is kept in the viscous state and not allowed to become fluid. Very thin steel is not best welded by the metallic arc process unless the edges are bent out parallel, in which case this process works nicely, very fast and generally better than any other metal yet developed.

The arc process is about the only way that malleable iron can be welded and any way realize all of its physical properties. Malleable iron or cast iron cannot be successfully brazed with the arc process but the ordinary iron electrode method gives us much better and dependable results that there is no occasion for the use of a bronze rod.

All the physical properties of cast steel can be realized by the arc process—tensile strength, cold bend, ductility, elongation and alternating stress; in fact, arc welding metal cast in very small quantities in its own electric furnace is very liable to be better than commercial cast steel. It is at least as good and tests made with flux coated electrodes by the Interborough Lines of New York City in 1918 before a committee composed of Interborough engineers, engineers of the Public Service Commission, and of the City of New York, resulted in the verdict that such an electrode deposit possessed all the properties of good cast steel. With bare wire cast steel can be welded, let us say about equal to unannealed casting but with flux coated wire results about equal to the best annealed casting can be obtained.

Fluxes are also useful in ridding the weld of such undesirable impurities as sulphur and phosphorus, both of which tend to produce a hard, brittle mass of metal in a weld. Moreover, all desirable impurities such as manganese and carbon burn out of the weld easily while sulphur and phosphorus persist.

Flux coated wire is speedier and more efficient than bare wire for three reasons: First, it requires less brushing, preparation and interrupting of the actual welding operation; second, the voltage across the fluxed arc is higher than across the bare rod, and the amount of work done is directly proportional to the amount of energy liberated at the arc. Hence, for the same current, the arc is proportionately faster due to the higher voltage; and there is less spatter and unnecessary oxidation with the fluxed electrode because the arc is concentrated or focused like a stream coming from a nozzle, whereas, with the unfluxed electrode, the arc shows a tendency to widen, much in the same manner as water coming from a hose without a nozzle.

In addition to cleasing of the weld, fluxed electrodes are the only known way of adapting alloys of steel to any desired analysis, the have been the only advance made in cast iron welding and for ordinary welding they are not more costly because the increased electrode cost is far more than offset by the direct saving in labor

not to mention the insurance of having the work done right the first time and always.

It has been found also that a greater proportion of the added metal is actually retained with flux coated electrodes than with bare electrodes. By comparing the weight of metal plus bare electrode before welding with the weight after welding, it has been shown that a portion of the electrode approximating 20 per cent is lost. With a flux covered electrode this loss is less than 5 per cent, indicating that more metal actually goes into the weld when using the coated electrode.

It should scarcely be necessary to defend the use of a flux coating at all. Every metal founder knows that without the proper fluxes he would be helpless, and could not produce a perfect casting. The electric arc welding process consists of casting metal on a small and highly concentrated scale and is so benefited by the use of fluxes to an even greater extent.

Welding although not perfect, is far better than other processes yet devised for joining metals but the present danger seems to lie in the expectation of too much of the casting. Advancement would appear to be along the lines of realizing average results and then use the best processes developed in order that the factor of safety may be increased.

It would be quite unexpected to find a method of producing ductility and elongation in a weld which is a casting equal to a forged section until some practical method of forging the weld deposit is realized.

Welding All Steel Automobile Bodies*

JOSEPH W. MEADOWCROFT†

If we were to turn back a score of years we should find relatively few commodities produced from light gage sheet metal and that the method of fabrication then in use was almost exclusively riveting. Riveting as a means of assembly caused much difficulty. Rivets were not driven tight. The rivet holes were over or under size; rivets were not driven in line with the axis of the center line of the rivet, and there were numerous other objections which we need not dwell upon here. It was due to the above conditions that so much stress was laid on the importance of finding a method of fabricating sheet metal products which would be useful in the construction of such commodities and which would yield a more substantial and economical product.

Electric spot welding is the method which has replaced riveting, and this method of fabrication has been applied very successfully, because the welds are strong, the production is large and all with lower cost and cleaner operation, and at the same time the capital

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†Superintendent, Edward G. Budd Mfg. Co.

investment in tools and the maintenance cost has undergone a notable reduction.

During the early days of electric spot welding sheet metal much difficulty was encountered due to the failure of manufacturers of sheet metal to hold sheets to a uniform gage. This gave the manufacturers of electric spot welding equipment the problem of building electric spot welding machines which would work by mechanical control in the switch, applying both power and pressure.

While this development work on welding machines was in progress many steel mills were attempting to solve the problem of rolling sheets so that they could be held commercially uniform, which would then give us a material and a method of fabrication suitable for use in the construction of railroad coaches, aeroplanes, automobile bodies, etc.

Spot Welding Extensively Used in Body Building

We were the first to adopt this method for manufacturing all-steel automobile bodies, and the first of these bodies were made in Philadelphia, June, 1912. This company is the first in the world to manufacture all-steel automobile bodies and the success of producing these was due to the confidence the founders of our company had in this method of welding.

While many other manufacturers of sheet metal commodities were more or less dubious about electric spot welding, and were using other methods, such as soldering, riveting, etc., we were continually developing many new and special welding jigs and fixtures for welding the various parts of the bodies. This enabled us to produce a uniform and economical product. Now we have become the largest users of welding equipment throughout the entire world.

In the design of an all steel body, much stress is laid on the design of the parts so as to secure the necessary rigidity into a minimum number of pieces so as to facilitate their ready assembly in the jigs and fixtures for welding. Welded joints and seams do not break open, nor do the metals wear upon each other, thus squeaks and noises are eliminated. The assembled bodies are light in weight, durable, free from any defective joints and present an exterior surface smooth and free enough from imperfections to permit good finishing. Any surface irregularities, such as blow holes in seams or improperly closed joints, would act as a reservoir for the finishing material, and if enameled and brought up to 450 deg. F., in a baking oven, would produce a blow or blister. The surface must be absolutely smooth, without depressions or cavities in which more than the standard thickness of enamel can flow, and so that the lacquers and color varnishes can be applied with the minimum amount of labor. A smooth, unbroken surface eliminated puttying or filling up of crevices.

When designing the various parts which are fastened together much stress is laid on the method of welding to be applied, and a strict standard is adhered to at all times. The size and construction of the various types of bodies produced for the many automobile companies plays a very important part in the amount of welding used, but the average amount of welds on open type bodies is as follows:

1000 to 1100 electric spot welds
70 in. to 80 in. acetylene gas welding.
10 in. to 12 in. metallic arc welding.

On the full vision all-steel sedan bodies, the average amount of welds is as follows:

1600 to 1700 electric spot welds
170 in. acetylene gas welding
11 in. to 12 in. metallic arc welding.

Development of Special Devices Useful in Spot Welding

The various stampings are formed in dies and assembled in special electric welding machines of our own design, which have many special attachments, enabling us to weld all parts or units together and hold them uniformly. It is with the aid or assistance of these special fixtures that we are able to hold all parts which have contours in their proper position while welding them. It also insures safe and sound welds. This permits us to make sufficient allowance at all times in the special welding fixtures for expansion and contraction which so frequently is a source of trouble in welding large bodies of metals together.

Considerable time is saved in handling and welding the parts as they are so assembled that sufficient welds are placed in a short time, permitting us to produce large quantities of bodies on a small number of machines. Regardless of the method of welding used in connection with the assembly in the above machines, no time is lost in the manufacturing operations because each operator does his particular part, finishing with his helper or helpers within a specified time.

Another feature of economy in producing in these specially built welding machines is that the welding operators get the highest efficiency in the assembly and welding in the various parts of the body owing to the fact that the stampings or parts are interchangeable. Many operations are done on conveyors regardless of the method of welding used, this being done without any loss of time in the operation.

All of the various parts of the body are clamped together in such a manner that we are assured of good contacts in making spot welds. This is very essential in electric spot welding steel bodies, as it is necessary to spot weld the various sections of the body together so that the indentions in the metal are more or less

eliminated. On some of the interior parts which are not exposed, the indentions receive no consideration, as it is not necessary to do any finishing work, but in all cases where welding is used, whether it be interior or exterior, whether parts are perfectly flat or shaped, we make the proper allowance as mentiond above for contraction at the point of welding so that the bodies are held in their proper shape and to their proper dimensions. This makes it possible for fenders and other accessories which are made to a correct shape, to be interchangeable.

Spot Welding Die Maintenance

In our daily production, 18,000,000 spot welds are made on standard and special electric spot welding machines, and the copper dies are designed under the supervision of the welding division, held to certain standards for shape and size of material and produced in quantities in the tool department. A stock of each copper die is kept in the tool booth in each assembly department, so that a quick exchange can be made at any time, but only a small supply of each die is kept in stock. This means we carry a small inventory of copper regardless of the vast amount of electric welding which is done.

TESTS

Consumption of Copper in Producing Electric Spot Welds on Sheet Metal 1/32-in. in Thickness

Material

2 copper electrodes—¾ in. dia., 2½ in. long.

Design

Forged out to ⅜-in. working end, and water cooled to within ½ in. of working end.

Weight at start of test	16.2 oz.
Finish	10.45
Loss	5.75

Production

Amount of spots 49120.

49120 spots ÷ 5.75 = 8530 spots per oz. of working copper or loss in welding and dressing up.

Electrode or Die Point

Actual loss through welding, filing and scrap 16.2 oz.

49120 spots ÷ 16.2 = 3052 spots per oz. of copper or each 1000 spots requires .33 oz. copper.

Standard Qualifications for Apprentices

The electric resistance spot welding operator welds on sheet steel usually 1/16 in. or less in thickness. He must be able to adjust his machine in such a manner as to insure standard spot welds.

The amount of welds produced per machine per man when ma-

chine is operated by hand or foot will average 10,000 to 25,000 spot welds daily, according to the size of piece or pieces to be welded.

Electric spot welding machines which are mechanically operated produce 150 to 175 spots per minute.

Men with mechanical experience or those who have worked around mechanical work are preferred.

1. Length of training time—1 week.
   Next advance is on production work, which is generally a piecework proposition and the wage earned by operators is governed by the class of work to be manufactured and the ability of the operator.
2. Age—18 to 25 years.
3. Height—Variable.
4. Weight—Variable.
5. Posture—quick.
6. Hands, legs and feet must be in good condition.
7. Eyesight must be in good condition.
8. Schooling—Grammar school, at least.

Electric resistance spot welding operators are more or less leaders in production, and it is essential that you have active, alert and ambitious men.

Instructions to Electric Spot Welding Operators

When Electric Spot Welding Apprentices receive their first instruction in the operation of an electric spot welding machine they should be instructed very thoroughly as to the safety devices and tools required to be worn or used.

First an apprentice should be very careful in the selection of clothing which he wears while operating a machine as an old torn shirt, coat, or in fact any piece of clothing which is in any way ragged, is apt to become ignited and cause a bad burn.

I would firmly approve the non-use of any cotton garments, or those which contain a mixture of more cotton than wool, as it has been the writer's experience to see a number of operators catch fire from sparks or flying molten metal falling upon a fuzzy surface of a shirt and apron. The regular grade of blue shirt commonly worn by workmen seems to me to be about the safest and cheapest garment that could be worn. The operator should also wear an apron of leather which is of the proper size to protect him from high on the chest to the knees, and also well around the waist towards the back. The operator should be instructed to wear his apron at all times, and not allow same to become oily or oil soaked without either having it washed off or replaced with another apron.

When the clothing is found satisfactory, much stress must be placed on the selection of a goggle as same should be so constructed that they are adjustable for the proper distance between the eyes, and also for the comfort of the temples or the part which is used

behind the ear to hold the goggle in place. The goggle should be well ventilated but at the same time should have the side shields and must be so adjusted that there are no crevices around the outside edge for the sparks or molten metal to enter between the face and the goggle.

There is a new phase of goggle wearing which can be considered favorable, as there is now on the market a satisfactory arrangement whereby men who must wear glasses for eye correction can be fitted up with goggles so that they may do welding or grinding, and also receive 100 per cent protection to their eyes, and also to their glasses.

The adoption of this particular type of equipment makes it possible for an employee to receive a pair of first-class frames fitted with lenses ground exactly to his prescription. These glasses are worn by him all day as a pair of shop glasses, and at the end of the day he may take them off and put on his regular pair which he no doubt would feel are better looking.

In consideration of the fact that these goggles are a standard article, and that the glass in the goggle is replaceable and also changeable with the standard goggles used by men not wearing glasses, it would seem to me that it is favorable that any man wearing or not wearing glasses could be instructed in welding.

From a standpoint of health, goggles should be issued only after being carefully sterilized, and should not be given or exchanged with any other operator or apprentice before being sterilized again.

After the apprentice is equipped with goggles, apron, and the proper clothing, he is instructed as to the various parts of the electric spot welding machine and their use. He learns how to prepare a die or electrode and to assemble same into water shank or die holder. After the dies or electrodes are assembled to the die holders, the apprentice is instructed how to adjust the electrode holder so that the upper and lower electrode or dies are placed in alignment. He is also impressed at this time with the fact that he should never strike an electrode or die with any hard substance to place them in alignment, as the copper is soft and the threads are apt to become loose, resulting in a leak.

The apprentice then receives instructions on the following:

1. How to attach special accessories to electrodes, so that same can be used on two or three welding operations.
2. How to file electrodes or die points to the proper diameter to correspond with the gauge metal to be welded.
3. How to know when his electrodes are becoming hot, and what action to take regarding same. This is simply a matter of water cooling and in case electrodes become heated, it simply means the clogging of water circulation. In cases of this kind, he should cease welding immediately, and have the water circulation looked into at once.
4. How to take care of the locks on the water shank holders

using the proper size wrench to lock water shanks or electrode holders in same, and under no conditions use a hard substance to place water shank holders in alignment or use a wrench on lock nut which is not properly fitted for same.

5. What to do when threads on electrodes begin to wear,
   a. He should never place string on same, as string is a non-conductor and under no condition should be used. When threads are worn on electrodes they are to be exchanged immediately.
6. Why he should never use dirty and blunt dies—they always give an unsatisfactory weld and cause much heating of both the switch and the transformer.
7. Why the regulator switch should never be changed while in the operation of welding—if same is done, connections are burnt out, making it impossible to use welding machine until repaired.
8. Why no material of any kind should be placed on transformer in electric welding machine, as same will cause a short circuit and burn out the transformer.
9. Why copper tubing should always be placed ¼ in. from the ends of electrodes, as when the tube is placed in water shanks and electrodes attached accordingly, if the tube is not assembled properly, and the above dimensions not held, the water gets hot, due to a pocket of steam being formed at this point of the electrode.
10. Why he should not attempt to use any rusty or scaly material as this causes unnecessary heating of transformers and switch, besides it will not permit making a standard spot weld. Many failures of spot welds can be attributed to this item and the apprentices are impressed with same.
11. The proper amount of pressure required so that the metal is drawn together before any heat is applied. This insures a standard spot weld.
12. Why he must always see that water shank holders are kept tight in water shanks as when same become loose they cause unnecessary heating of the transformer and it is impossible to get the proper amount of heat.
13. Why he must watch connection wires on switch, for if insulation becomes worn off, the bare wire comes in contact with switch frame or machine frame, causing a waste of power and an electric shock to the operator.
14. How to assemble contact plugs so that they are placed a uniform distance apart, and that they are filed to a flat face at connecting point so that same do not cause unnecessary heating.

15. The six basic causes that make repairs to electric spot welding machines necessary:
    a. Insufficient or improper lubrication.
    b. Presence of dirt on bearing surface.
    c. Misuse of machine.
    d. Imperfect adjustments.
    e. Vibration.
    f. Unavoidable wear.

    Proper supervision of machines and systematic inspection will take care of the first four causes—lubrication, dirt, misuse and adjustments. The fifth cause—vibration is a result of the first four causes unless the design is seriously at fault.

Spot Welding Practice

When two metal sheets are spot welded together in accordance with the customary practice, the fusing of the metal and the pressure applied results in the formation of a low spot weld. In other words, the thickness of metal at the weld is slightly less than the combined thickness of the two overlapping sheets at an unwelded portion. This difference in thickness is not very great, but where a finish is to be applied to the surface of one of the sheets, it is objectionable since these low spots give an undesirable appearance to the finished surface. To overcome this difficulty it has been the practice to eliminate these low spots by grinding off the surface so as to bring it down to the same level as the weld. This practice is slow and costly, but heretofore it has been necessary in order to produce a satisfactory surface. This condition of low spots in sheet metal is a very serious item, and much depends upon the method of handling the pieces while welding as to whether or not you can produce the so-called low spots in such a manner as to have only a minimum amount of finishing.

In some cases where spot welds are made on radii it is possible to spot weld metal sheets together in such a manner as to cause part of the metal at the weld to project or protrude above the surface of the surrounding metal by forming a small teat or projection at the weld. The weld is so made that this projection protrudes from the surface to be finished—that is the surface in which any low spots would be objectionable as stated heretofore. After the metal sheets have been joined together by a series of welds made in this manner the small teats or projections are removed in any suitable manner—as, for instance, by grinding them down to the level of the surrounding surfaces. This surface then has no low spots and its appearance when finished will be very desirable.

The lower electrode is of the form commonly used on all makes of electric welding machines and the upper electrodes are of the usual form except that they have a small conical recess arranged centrally in the lower end of electrode. The metal sheets are in-

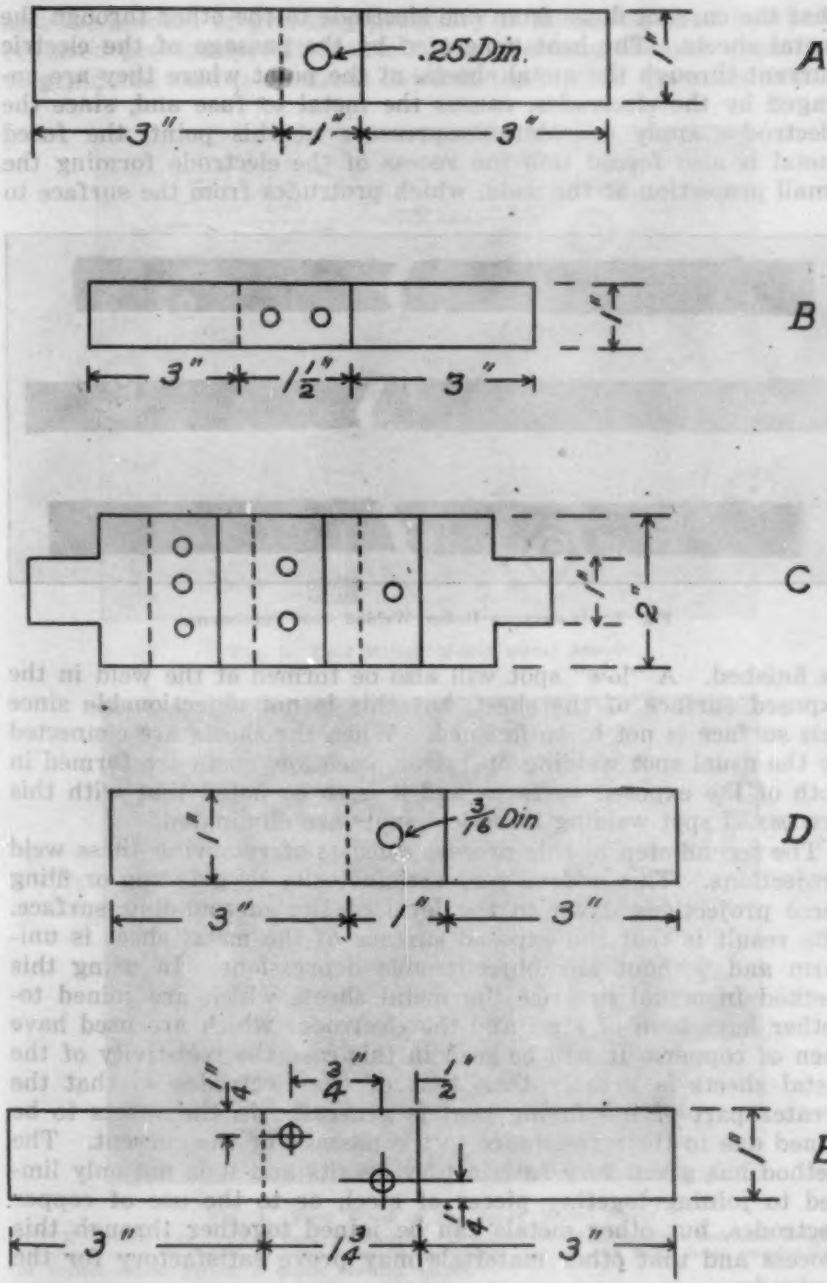


Fig. 1.

serted between the electrode having the recess. The electrodes are caused to approach each other and engage and clamp between the overlapped metal sheets, the electrical circuit being so closed so

that the current flows from one electrode to the other through the metal sheets. The heat generated by the passage of the electric current through the metal sheets, at the point where they are engaged by the electrodes, causes the metal to fuse and, since the electrodes apply considerable pressure at this point, the fused metal is also forced into the recess of the electrode forming the small projection at the weld, which protrudes from the surface to

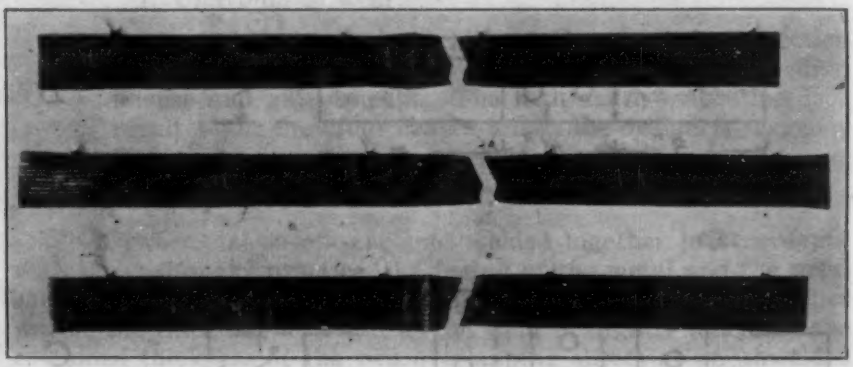


Fig. 2. Resistance Roller Welded Test Specimens.

be finished. A "low" spot will also be formed at the weld in the exposed surface of the sheet, but this is not objectionable since this surface is not to be finished. When the sheets are connected by the usual spot welding operation, such low spots are formed in both of the exposed surfaces and it is to be noted that with this process of spot welding these low spots are eliminated.

The second step in this process consists of removing these weld projections. This is done very satisfactority by grinding or filing these projections down to the level of the surrounding surface. The result is that the exposed surface of the metal sheet is uniform and without any objectionable depressions. In using this method in actual practice the metal sheets which are joined together have been of steel and the electrodes which are used have been of copper. It will be seen in this case the resistivity of the metal sheets is greater than that of the electrodes so that the greater part of the fusing heat is generated in the sheets to be joined due to their resistance to the passage of the current. The method has given very satisfactory results and it is not only limited to joining together pieces of steel, or to the use of copper electrodes, but other metals can be joined together through this process and that other materials may prove satisfactory for the electrodes.

It is to be noted that by the use of this process in cases where one of the surfaces of these welded members is to be finished, the work can be accomplished at a lower cost than heretofore. The welding operation is no more costly and no slower than heretofore

and the amount of grinding necessary is much less than has been required previously. It is a much simpler and cheaper operation to grind the weld projections down to the level of the surrounding

Fig. 3. Cold Rolled Monel Metal Sheet.

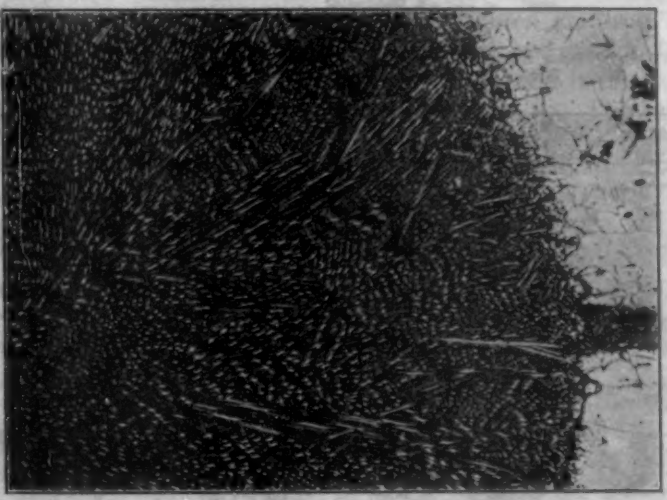


Fig. 4. Spot Weld in the same Monel Sheet.
NOTE: Weld has typical cast structure. The line of demarkation between original structure and the weld is very marked, probably due to the high heat conductivity of Monel metal giving a quick chilling effect.

surface than to grind the surface down to the level of the "low" spots at the welds.

As each man finishes his training, he is placed in one of the assembly departments under the supervision of one of the welding

foremen, who is responsible for the quality and quantity of the work turned out by the apprentice. The apprentices are advanced from time to time in accordance with their ability to do higher

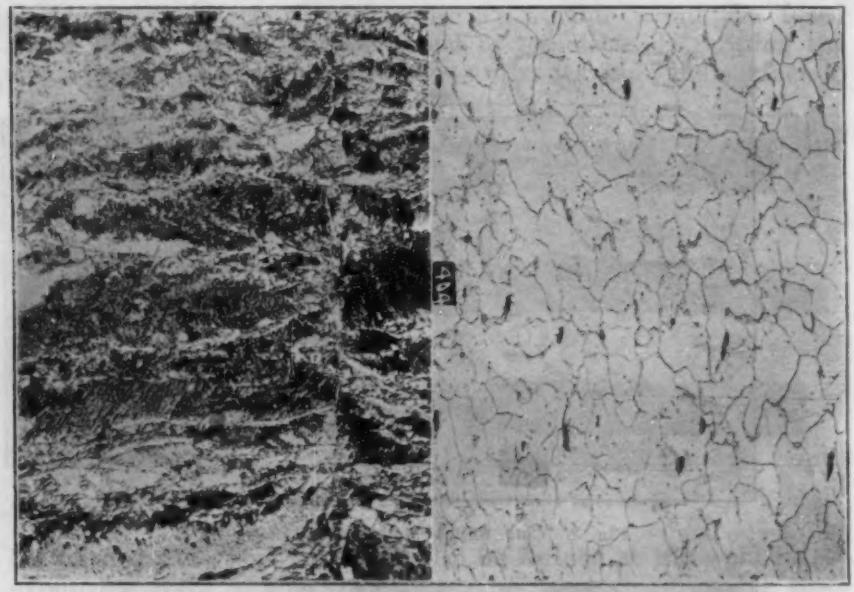
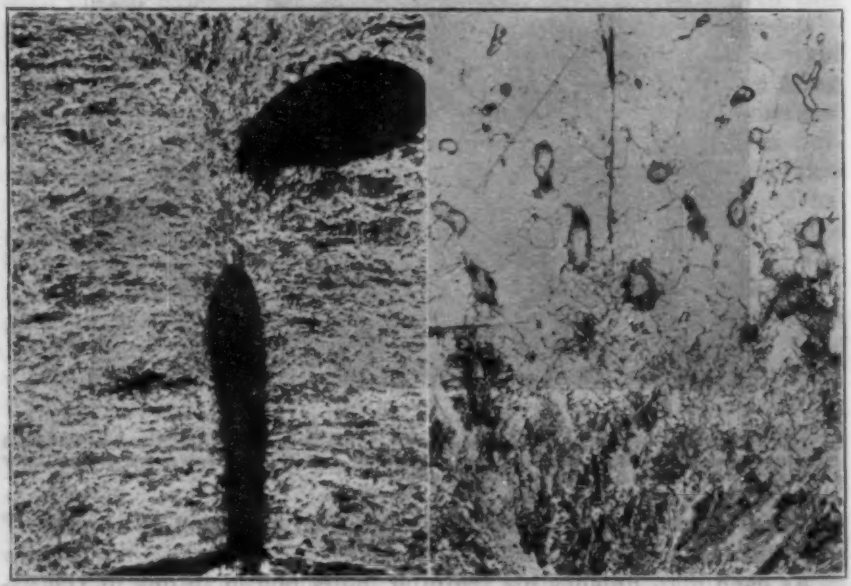


Fig. 5.

Spot Weld in Sheet Steel Typical Cast Metal Structure.

Typical Structure of Sheet Steel as Used in Shop.



Gas Pocket or Blow Holes in Spot Weld.

Segregations caused by high heat of Welding.

class work, and as all operators are paid in accordance with the class of work they are doing, there is always a goal to work for, which obtains the best results for both parties.

The time study of welding operations is done by men who are thoroughly familiar with welding operations. They see that the operations are so separated that they can be performed in a highly efficient manner. Each and every operation is inspected, which means that the accuracy of the previous operation is assured. The inspectors are also men who have had more or less training in the art of welding, and at various time periods they make inspections of welds while they are being made instead of after the welds are finished. By handling the inspection of welds in this manner, the inspector not only holds the quality of the welds to a high standard, but assists the welding operator regardless of the operation, to become more efficient in obtaining a production output satisfactory in both quantity and quality.

Strength of Spot Welds

The question is frequently asked, how do spot welds and riveted joints compare in strength? It is not my intention to go fully into this question here, but I may say briefly that there is no substantial difference in our use of them. If two thin pieces of metal and two thick pieces of metal be riveted with rivets of the same size there is a certain thickness of metal below which all failures will arise through the tearing of the sheet and above which failures will be due to the shearing of the rivet. The same is true of spot welds if the area of the spot weld be held constant. The table below gives test results on spot welds applied to sheets of different thickness, but the area of the weld itself is nearly constant. In the examples given when the thickness of the metal is above 0.062 in., the weld itself undergoes shear. Had the area of the weld been greater, the weld would have failed in shear only with a greater thickness of metal. Exactly the same thing happens with rivets. When the section of the rivet is small and that of the sheet large, it is always the rivet which fails.

General Description Roller Welded Test Specimens (*See Fig.* 2.)

General Description—Piece of Sheet Steel Welded by Roller Welding Machine.

Test Metal—0.034 in. thick. The welded portion—0.055 in. thick.

The tensile strips pulled were 1 in. wide.

Welded Pieces

Yield Point	Tensile Strength	Stress on Weld
32,650 lb./sq. in.	44,700 lb./sq. in.	27,650 lb./sq. in.
29,100 lb./sq. in.	44,250 lb./sq. in.	27,350 lb./sq. in.

The breaks occurred very close to weld.

Strips Not Welded

Yield Point	Tensile Strength
36,150	47,600
35,300	46,500

The lower yield point of the welded pieces is probably due to local heating during the welding operation.

TENSILE TESTS ON RIVETS IN SHEET METAL*

Single Rivets

These rivets were headed by machines as used in the shop. Backing up tool was a Diamond Knurled Flat Surface. Force applied to head of rivet by an air hammer fitted with die made to suit mushroom head of rivet. (See A, Fig. 1).

Metal Thickness	Load, Lbs.	Shear Stress on Rivet, Lbs. per Sq. In.
Steel — .025	840	17,100 — Rivet pulled out of strip.
Steel — .039	945	19,300 — Rivet pulled out of strip.
Steel — .048	1,500	30,600 — Rivet pulled out of strip.
Steel — .059	1,395	28,400 — Rivet pulled out of strip.
Steel — .070	2,010	41,000 — Rivet pulled out of strip.
Steel — .088	2,175	44,300 — Rivet sheared off.
Monel — .061	2,590	52,800 — Rivet sheared off.

Two Rivets (See B, Fig. 1).

Metal Thickness	Load, Lbs.	Shear Stress on Rivet, Lbs. per Sq. In.
Steel — .039	1,355	13,800 — Metal strip broke.
Steel — .057	2,460	25,300 — Metal strip broke.
Steel — .088	4,265	47,400 — Metal strip broke.

*Laboratory tests made by George J. Farnsworth.

TENSILE TESTS OF SPOT WELDS IN SHEET METAL

Metal Thickness	Area of Weld	Load, Lbs.	Shear Stress on Weld per Sq. In.
Steel — .031	.048 sq. in.	800	16,700 — Sheet broke around weld.
Steel — .043	.055 sq. in.	1,470	26,800 — Sheet broke around weld.
Steel — .050	.051 sq. in.	1,230	24,300 — Sheet broke around weld.
Steel — .062	.054 sq. in.	2,140	39,600 — Sheet broke around weld.
Steel — .078	.049 sq. in.	2,210	45,000 — Sheet broke around weld.
Steel — .088	.0594 sq. in.	2,820	47,400 — Sheet broke around weld.
Monel — .062	.0314 sq. in.	1,260	40,000 — Sheet broke around weld.

These were single spot welds. Test pieces were similar to that shown in diagram for riveted test pieces.

Monel metal sheet spot welded as in diagram Fig. 1-C. Thickness of metal — .062.

Four pieces—held together at one point by 3 welds, at another point by 2 welds, and the other by 1 weld.

Pulled in Olsen Tensile Test Machine—place with 1 weld broke first, the 2 welds broke next; the strip tore before the 3 welds could be loaded to breaking point.

No. Welds	Area of Weld	Load	Shear Stress per Sq. In.
1	.041	1,960	49,000
2	.039 } .031 } .070	2,800	40,000
3	.110	3,230	29,400

TENSILE TESTS ON RIVETS IN SHEET METAL

Rivets used were 3/16-in. diameter and were mushroom headed both sides. Riveting done with air hammer. (See Sketch D, Fig. 1).

Single Rivets

Metal Thickness	Load, Lbs.	Shear Stress on Rivet, Lbs. per Sq. In.
Steel — .031	705	25,320 — Rivet pulled out of strip.
Steel — .043	945	34,400 — Rivet pulled out of strip.
Steel — .050	1,110	40,200 — Rivet pulled out of strip.
Steel — .062	1,490	53,900 — Rivet sheared off.
Steel — .078	1,610	58,200 — Rivet sheared off.
Steel — .088	1,325	47,800 — Rivet sheared off.
Monel — .062	1,360	49,200 — Rivet sheared off.

Two Rivets (See Sketch E, Fig. 1)

Same diameter rivets used—same type head.

Metal Thickness	Load, Lbs.	Shear Stress on Rivet, Lbs. per Sq. In.
Steel — .062	1,770	12,850 — Metal tape and rivets pulled out at side of holes.
Steel — .088	2,945	21,300 — Metal tape and rivets pulled out at side of holes.

Safety in Steel Transportation Products—all Steel Welded Automobile Bodies

Although all automobile manufacturers at present are not using welded all-steel bodies, neither do all of our railroads at present use all-steel coaches and Pullman cars, yet the all-steel automobile body holds the same position from a safety standpoint, with relation to the wooden frame composite body, as the all-steel coach and Pullman cars hold to the wooden cars.

Our recollections of railroad disasters picture to us the results very clearly from the use of steel or wooden cars. The wooden cars crush, break apart and usually burn with a resultant deplorable loss of life, whereas the steel coaches retain their form, and, although, perhaps somewhat distorted, they do not break apart and the occupants, therefore, are afforded the maximum of protection.

Welded all-steel automobile bodies have been known to roll down mountain sides and turn over and stand on their roofs without damage to the structure of the body.

The time is not far distant when the automobile buying public will demand the safety and protection of welded all-steel automobile bodies and from year to year we shall see more automobile manufacturers using this modern development in automobile body structural design to keep pace with the rapid advance of civilization.

Thermit Welding Development*

J. H. DEPPELER†

In talking on Thermit Welding, I usually find it necessary to give a very brief description of the process and to apologize for this constant repetition, and I feel that in this talk it will again be excusable because we must remember that the Thermit Welding Process, although in our estimation just as important as either the Oxy-Acetylene or Electric Welding Processes, is nevertheless not so widely used and, therefore, in every audience we find some few not thoroughly familiar with the Process and who, without this review, would not easily understand the paper to follow.

In making a Thermit weld, the operator provides a gap between the fractured ends, and pours into this gap and around the ends a very pure, high grade steel which is so hot that it fuses the fractured ends and solidifies with them. To accomplish this, of course, the fractured ends must be surrounded with a refractory mold and a highly superheated steel provided. This steel is obtained by means of the material called Thermit.

In the production of ordinary steel, carbon is used to reduce the iron ores and oxides and, although carbon in one form or another is a very cheap reducing agent, it requires the expenditure of a great deal of energy in the form of heat to cause this reduction to take place and thus to form the molten steel. In the Thermit Process, however, aluminum is the reducing agent and after the chemical reaction between iron oxide and aluminum is started at one point, it will spread rapidly through the mass in an exo-thermic reaction, producing in 30 seconds or so a mass of superheated molten steel with a molten slag of aluminum oxide. The temperature of this molten steel is almost double the temperature of ordinary molten steel and its superheat or the temperature above the melting point is given up to the sections to be welded, melts them and solidifies with them. Except where this superheat can be used it is in most cases not practical to produce steel by this process because of the expense of the aluminum as compared with the more common reducing agent—carbon—but the entire Thermit Welding Process is based on the use of this superheat and it has been developed to a high state of perfection. Since we are dealing with an expensive reducing agent (aluminum), which in itself makes the steel too expensive for ordinary use in the production of castings, etc., we find it desirable to produce at a slight additional expense the highest grade steel possible and, therefore, select the purest form of iron oxide treated to bring it to a uniform consistency—both in chemical composition and physical size of particle—and mix this with the pure aluminum in the manufacture of Thermit instead of using many of the cheaper iron ores or oxides. The

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†Chief engineer, Thermit Dept., Metal and Thermit Corp.

result is the production of steels of high chemical purity and of great physical strength.

By this same method of aluminum reduction, we produce the Carbonfree Metals, such as Manganese, Chromium, Titanium, Vanadium, Tungsten, Cobalt and Molybdenum, some of them as practically pure elements and others alloyed with iron. In general, these metals are produced in the same way by mixing prepared oxides of the element with aluminum, starting the reaction and thus producing the element in its molten state. It is evident from this that it is a comparatively simple matter to design Thermit mixtures for welding operations which will produce any desired alloy steel so that, for instance, the Carbon, Manganese, Chromium and Vanadium content may be varied at will and can be controlled within a fraction of a per cent.

At previous meetings of the Society, we have read papers reviewing in general the progress in Thermit welding and in these have told how in the earliest Thermit welding practice a two part, dry sand mold previously prepared on wooden patterns was clamped on to the section being welded, after the section had been warmed slightly to eliminate surface moisture, and how then the Thermit steel was tapped into this mold, sufficient steel being used to bring the parts to the welding heat and fuse them together. The quality of this weld was anything but good and the first real progress made in Thermit welding resulted from the development of a means of preheating within the mold wherein the sections were brought to a bright red heat and the mold dried out in the same operation. This resulted in an immediate improvement in the quality of Thermit welds and in the saving of considerable amounts because the preheating enabled smaller amounts of Thermit to be used per weld. After this, the practice remained fairly constant during the war period and the design of the Thermit weld called for a gap between the ends of the sections of a width equal to one-fourth the thickness of the section and a collar around the ends, whose width was equal to the thickness of the section and whose thickness at the center was equal to the gap or one-fourth the thickness of the section. Large risers were used in order to feed the shrinkage of the casting and following the regular steel casting practice. In Thermit welds made in this way, the parent metal was fused on the outsides of the sections practically to the outer edges of the collar, and this fusion extended in broad sweeping lines which approached each other at the center of the section, at which point they were separated for a distance of about twice the original gap.

Thermit Welding had gradually increased in its importance and was used by this time in the welding of locomotive side frames, the stern frames of vessels and in the repair of broken crankshafts and most other important heavy castings and forgings. It had a great advantage over any other welding process in that the weld was made all at one time and, therefore, most of the internal

shrinkage strains were absent. There was no tendency to warp the pieces and it was necessary only to allow for the shrinkage of the weld along the axis of the piece, but regardless of the popularity of the process, it was very discouraging at times because of the frequent presence of blow-holes in the Thermit welds. In steel casting practice, this would not have been so bad as it would have resulted only in the rejection of certain castings and the making of others, but in this emergency repair work with dry-dock charges, for instance, of $500 to $900 per day and with the Thermit welders working night and day to complete the operation, the discovery of blow-holes upon the completion of the weld and the necessity of cutting out the weld and making it over was most disheartening to say the least. This was equally so in crankshaft repairs where, after welding, all the excess metal was machined off and where in the machining blow-holes were uncovered and all the previous welding and machining expense lost. The first important research, therefore, was on the cause and elimination of these blow-holes and, in a previous paper, we have shown how this was accomplished. This will be briefly reviewed here.

The cause of blow-holes in most castings, neglecting improper design of mold, is probably oxides in solution in the steel and the cure is the elimination of these oxides. This resulted in the development of many deoxidizers which are universally used in steel casting practice. In Thermit steels, however, it was evident that there was always an excess of the most important deoxidizer (aluminum) and that this, therefore, could not be the cause of the blow-holes in Thermit welds. After considerable research, it was found that the real cause was not in the Thermit steel itself but rather in the molding material used. It must be remembered that the pouring of steels at temperatures almost double their melting point had not previously been practised and that, therefore, molding materials which were suitable for ordinary foundry practice might not be suitable for Thermit welding. These molding materials were usually mixtures of sand and clay, and it was found that the best clay available fused at about 2500 deg. Fahr., or less than half the temperature of Thermit steel. It was evident, therefore, that the Thermit steel entering the mold would quickly fuse the clay of the molding material on the inner surface of the mold, and it was found that this fusion was accompanied by the formation of considerable gas which would try to escape either through the molten Thermit steel or through the mold itself, following the lines of least resistance. With the dense molds then in use, practically all of the gas had to escape through the molten steel of the weld and, in most cases, some of this gas was trapped as the weld solidified. The solution was found in the selection of the best clays, the use of a minimum of these and the design of a molding material which would have the maximum porosity after baking so that the gases could escape through the mold. The formula for this molding ma-

terial was given to all users of Thermit and the molding material itself offered for sale. With proper Thermit welding practice and with this molding material, the troubles from blow-holes disappeared.

In a subsequent paper, we discussed the developments in rail welding, in which it was discovered that most of the fusion of the rail section was caused by the wash of the Thermit steel by the surfaces rather than by the high temperature of the Thermit steel lying near the parent metal and the economy was effected by designing the rail molds in the form of what we term the Center Pour Weld, which tood advantage of this wash most effectively and cut the cost of Thermit rail welding more than in half so that, for even the heavy sections, only 13 to 15 lb. of Thermit were required per rail weld instead of the 25 lb. to 30 lb. previously used, and advantage was taken not only in the saving of Thermit but also in the use of smaller molds and smaller crucibles. These various economies brought the cost of the Thermit rail welds down to about $6 to $9 apiece, where they therefore cost no more than any of the other methods of joining rail ends with the great advantage of the entire elimination of the rail joint.

We now come to the newer developments in our research and those which have not previously been discussed before your Society. The most interesting of these is the elimination of an internal defect which, for want of a better name, we have called "cleavage plane." This defect was discovered in a test run for the purpose of securing the approval of Lloyd's Register of Shipping for the use of Thermit welds on stern frames and other important structural parts of ships classified by them; and in these tests, which were run at the Bethlehem Steel Co., Steelton, Pa., the welds were broken under a drop after all excess metal had been machined off and it was discovered that there existed an area just below the axis of the piece on a vertical plane running through the middle of the gap where the metal had been torn apart during solidification and around which the crystals had been very much overstrained. An examination of the fractures showed what appeared to be a dull, gray looking material at this point surrounded by the regular shining crystals of fractured steel. In some cases, this area was more prominent than in others but its existence was always found by the comparison of tensile strengths of test coupons taken from various parts of the weld. A careful study of the macro structure of Thermit welds proved what was really most logical and, that is, that the Thermit welds solidified first across the gap between the sections practically on the axis of the pieces and that freezing was progressive from this point outward, and that the part last to freeze was the collar surrounding the Thermit weld. It was immediately evident, therefore, that the large risers used in the Thermit welding practice were not necessary because the weld freezing from the inside toward the outside was just the reverse of the direction of freezing in ordinary casting practice. The function of the

riser in Thermit welding, therefore, was simply to act as a vent at the top of the mold and to feed the shrinkage of the top part of the collar which was probably the last to freeze. It was discovered that the part of the weld first to freeze coincided with the place where this cleavage plane existed and it was evident, therefore, that as the weld first started to solidify, some force existed which tended to tear this newly frozen section apart. Further research showed that this freezing at the center of the weld occurred within a very short time after the weld was poured, the sections being welded acting as chills and carrying the heat away very rapidly. It was found, further, that the outer fibers of the sections being welded would not reach their maximum temperature during preheating and not until an appreciable time after the weld was poured. In other words, the heat from the Thermit steel collar and from the riser continued to penetrate the solid metal of the parts being welded for some time after the weld was poured, causing these parts around and adjacent to the collar to continue to grow in length, even after the center portion began to solidify. It was this force, therefore, that acted like an enormous jack and tore the center section apart. In talking of this tearing apart in this discussion, it is, of course, clear that this is merely a matter of degree and that in many cases the cleavage plane was not actually opened but merely badly over-strained. Many ways were tried to overcome this internal defect, most of which consisted of changes in design, which tended to feed the shrinkage of this internal part of the weld. The extra molten metal added on the outside simply aggravated the condition and led us to understand the real cause. Obviously, there are only two ways by which this internal defect could have been overcome: first, by increasing the gap between the ends to be welded to a maximum so as to reduce the ratio of heat on the outer fibers to the heat along the axis and, second, to decrease the gap between the ends to a minimum at the same time decreasing the excess heat in the collar and in the riser so that in this way the ratio between the heat on the outside and the heat at the axis would be more nearly uniform. This latter way was tried because the other would tend toward an uneconomical use of Thermit and it was found that by a careful proportioning of the gap, width and thickness of collar, and by reducing the riser to a minimum, the cleavage plane was eliminated, so that test coupons taken from all parts of a Thermit weld vary only a fraction of a per cent. The new macro photographs do not show the broad sweeping curves of fusion which were typical of the former Thermit practice but rather straight fusion lines to within an inch or so of the outside portions of the section.

From an engineering standpoint, this elimination of the cleavage plane was a great step in advance and because the new proportioning of the parts so definitely accomplished this object, it was naturally found that the idea was patentable. But great as was the result from an engineering standpoint, imagine in how much better

a position the Thermit weld immediately was from a standpoint of economy, because this new design enables us to make a Thermit weld using less than half the amount of Thermit previously used and this because of the coincident saving in crucibles, size of mold and labor or ramming the mold actually cuts the cost of welding in half, makes it economical to extend the process to the lighter sections and in the steel mill, for instance, to extend the use of Thermit to great numbers of parts which previously could be almost as cheaply scrapped and re-made. The operation has met with a great deal of approval in the railroad shops and steel mills, and at present the Corporation's main difficulty is to carry the new ideas as rapidly as possible to the great number of Thermit welders.

In the above, we have only touched lightly on the effect of this change on the crucible cost, and this really deserves more attention because you may not realize that the crucible to contain a steel of so high a temperature must be very carefully made and, because most of the refractories dissolve to some extent in steel at this temperature, the highest grade, dead burned magnesite must be used. A crucible lining of this magnesite lasts in the case of small crucibles for forty or fifty reactions, but in the case of large crucibles holding 600 lb. or 700 lb. of Thermit, the lining lasts for only four or five reactions. The new methods have made this crucible problem much less important because in the big welds where two or more of the largest crucibles were used, only one is now necessary, and, where one large crucible was previously used, a much smaller one can now be used, the smaller one costing less in first cost and much less per reaction because of its longer life.

There is another development in Thermit welding which the Corporation has been working on for some time, the principle of which has been fully developed, which is also covered by patents and has been in successful use. This development is in the nature of an improvement in the crucibles and is very interesting although all Thermit users cannot as yet take advantage of it.

In the Thermit reaction, there is made in a very short space of time a mass of molten steel and a mass of molten slag of aluminum oxide, and this aluminum oxide is fused alumina, one of the best refractories known. During the brief interval of reaction, this molten steel and molten alumina are made in all parts of the crucible and if the conductivity of the walls of the crucible is sufficient a certain thin layer of this alumina will adhere to the walls and form an effective protection between the Thermit steel and the crucible wall. We have in this way developed crucibles made of various metals of relatively high heat conductivity, the most practical of which is probably steel, and have so designed the thickness of the crucible wall that it will cause this thin layer of alumina to freeze on its inner surface and not allow the crucible wall itself to be washed away. A crucible so designed without any lining at all will, as far as we know, be practically ever-lasting. Such crucibles have been in use for over 500 reactions and are just as good today as

when they were made. The alumina or slag gradually builds up on the inside wall of the crucible and after a time has to be removed, when the operation starts over again just as with a new crucible. We naturally have developed the small sizes first, as the thickness of wall at the various diameters is a matter of experiment. The things which have caused a delay in giving this to the Thermit welders have been principally due to inequalities in the crucible wall caused by segregation in the steel castings. These difficulties are now being overcome, so that we hope shortly to have the making of these crucibles on a practical manufacturing basis so that they will be a benefit at first to all of our Rail Welding customers and subsequently to the users of the larger sized crucibles in the Locomotive Shops and Steel Mills. Such a crucible, carefully designed, need not be noticeably heavier than the former magnesite lined crucible and, instead of having to be handled carefully in fear of breaking the lining, the steel crucible can be handled roughly without ill effects.

In conclusion, I want to just hint at the enormous amount of work that has already been done in the improvement of the physical qualities of Thermit steel and predict that the future will show that, in the Thermit reaction, steels can be produced which will have very unexpected properties. Certainly, in this mixture of practically pure aluminum and practically pure iron oxide, we have a basis on which to work which is very different from that which starts with the very impure materials which enter the blast furnaces and which are gradually purified to satisfy the needs of Commerce. We have already reached points in Thermit steels where, without work or heat treatment, the cast Thermit steel will exhibit such properties as 110,000 lbs. per square inch ultimate strength with 2% or 3% elongation in 2″, or the other extreme of an ultimate strength of 55,000 lbs. per square inch with 40% elongation in 2″; and these cast steels are so pure that they invariably fracture through grains instead of along grain boundaries as is the case with ordinary cast steels, so that a Thermit weld must not be considered as a cast joint in the middle of forged steel pieces because this Thermit cast steel has all of the physical properties of the forging and resists shock just as easily. Certainly, the future of Thermit welding seems bright and the many applications ever increasing.

Destruction Test on Gasolene Cracking Still*

C. C. JOYS, JR.†

Bursting Test—April 28.

In order to perfect and experiment on our Electric Arc Welding in heavier thicknesses of steel, we welded a shell 2½ in. thick, 10 ft. 6 in. long, by 5 ft. inside diameter.

This shell was made of four plates, welded together with four longitudinal welds. (See Fig. No. 1.)

When this was completed, it occurred to us that it might be interesting to some of our friends, as well as beneficial for future use to us, to run a destruction test on this vessel, and gather all information as to strength, expansion, etc., possible.

We, therefore, welded a steel head 2⅝ in. thick, made of nine welded sections, fitted with a regulation flange and gasket, the size specified on Cracking Stills we propose to manufacture, to one end.

To save time and expense, we had a cast steel head made, 3½ in. thick, and welded this to the other end. This head was an annealed casting of the highest quality.

The accompanying photographs will show all the details of the above construction.

On April 28, the following refinery officials and engineers witnessed the bursting of this vessel by hydrostatic pressure:

J. G. Alther, Universal Oil Products Co., Chicago, Ill.
H. P. Benner, Universal Oil Products Co., Chicago, Ill.
Dr. G. Cash, Standard Oil Co. (Indiana), Chicago, Ill.
A. F. Colling, The Texas Company, New York, N. Y.
E. R. Davis, The Texas Company, Port Arthur, Tex.
T. G. Dellinger, The Texas Company, Port Arthur, Tex.
R. L. Duff, Standard Oil Co. (New Jersey), Elizabeth, N. J.
J. E. Evans, Standard Oil Co. (Indiana), Chicago, Ill.
J. F. Hewson, Standard Oil Co. (Indiana), Chicago, Ill.
W. H. Hough, Standard Oil Co. (Indiana), Chicago, Ill.
R. R. Herrick, Universal Oil Products Co., Chicago, Ill.
L. C. Huff, Universal Oil Products Co., Chicago, Ill.
F. T. Manley, The Texas Company, Houston, Tex.
F. P. Risdon, The Texas Company, Houston, Tex.
L. L. Rebber, Union Oil Company, Los Angeles, Cal.
Wm. Shanks, Roxana Petroleum Co., St. Louis, Mo.
W. Sweringer, The Texas Co., Port Arthur, Tex.
T. D. Tifft, The Sinclair Refining Co., Chicago, Ill.
A. F. Wolf, California Edison Company, Los Angeles, Cal.

Result:

At a pressure of 4700 lbs. an oval piece 4 ft. 6 in. by 3 ft. 6 in. from the cast steel head was blown 50 ft. in the air.

*Reported to Pressure Vessel Committee, A. B. W.
†Manager of Sales, A. O. Smith Corporation.

Fig. 1. View of Gasoline Cracking Still manufactured by the A. O. Smith Corporation.

All welds held and showed no leaks whatsoever, the balance of the vessel being intact and still standing.

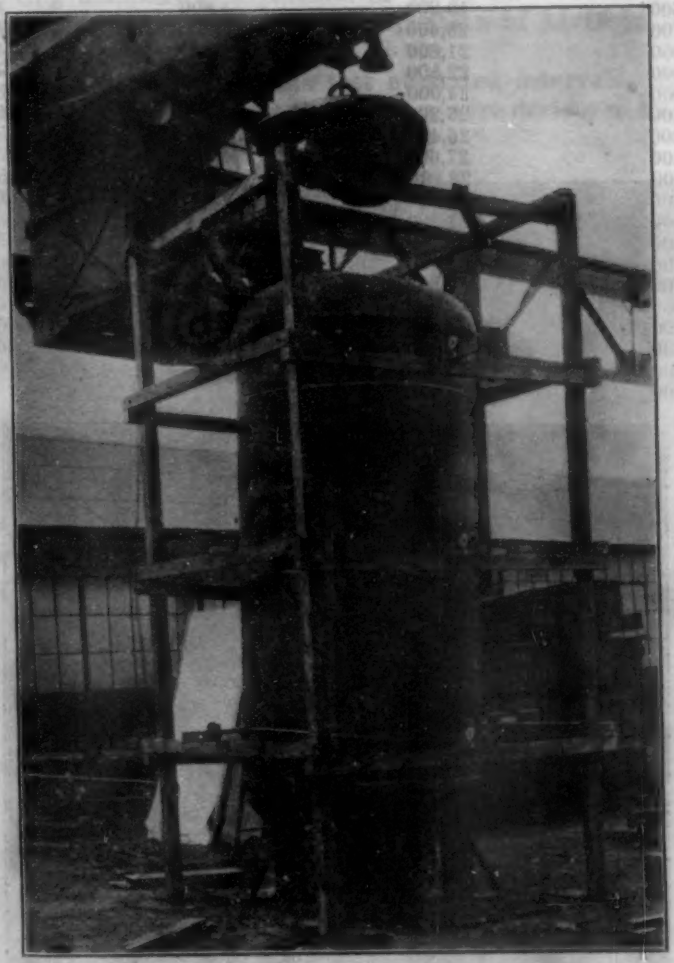

Fig. 2. Section of the still after testing. Portion of cast steel head blown off during test held by crane.

The pressure of 4700 lbs. is equal to a fiber stress of 56,400 lbs. as the accompanying chart No. 1 will show.

$$\text{Stress per square inch} = \frac{\text{Diam. x Gage Pressure}}{2 \times \text{Wall Thickness}}$$

$$= \frac{60 \times \text{Gage Pressure}}{2 \times 2.500}$$

Gage Pressure	Fiber Stress	Gage Pressure	Fiber Stress
500	6,000	3,500	42,000
1,000	12,000	3,600	43,200
1,500	18,000	3,700	44,400
1,600	19,200	3,800	45,600
1,700	20,400	3,900	46,800
1,800	21,600	4,000	48,000
1,900	22,800	4,100	49,200
2,000	24,000	4,200	50,400
2,100	25,200	4,300	51,600
2,200	26,400	4,400	52,800
2,300	27,600	4,500	54,000
2,400	28,800	4,600	55,200
2,500	30,000	4,700	56,400
2,600	31,200	4,800	57,600
2,700	32,400	4,900	58,800
2,800	33,600	5,000	60,000
2,900	34,800	5,100	61,200
3,000	36,000	5,200	62,400
3,100	37,200	5,300	63,600
3,200	38,400	5,400	64,800
3,300	39,600	5,500	66,000
3,400	40,800		

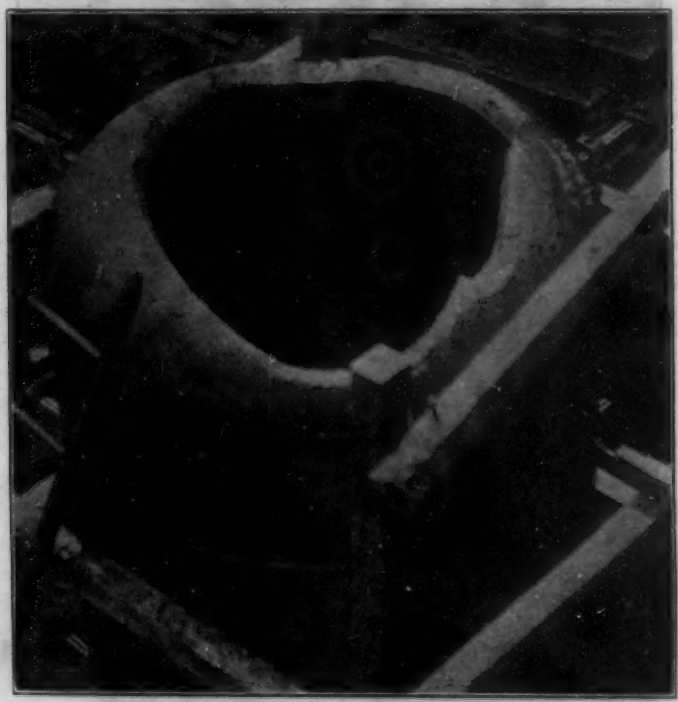

Fig. 3. View of top showing hole in cast steel head.

The scaffold shown in the photographs served the purpose of a support for twelve expansion indicators. There were also three steel tapes with sliding friction clamps for measuring the girth expansion.

All of these devices were either wrecked or thrown out of ad-

justment by the broken top when it descended alongside the tank, with the exception of two girth bands.

The center band indicated that the vessel expanded 15/16 in., representing diametrical expansion of 19/64 in.

The top girth band indicated an expansion of 11/16 in., or diametrical expansion of 7/32 in.

We took photographs of this test at stated intervals, showing the pressure gage reading, but these plates were destroyed by water when the vessel burst.

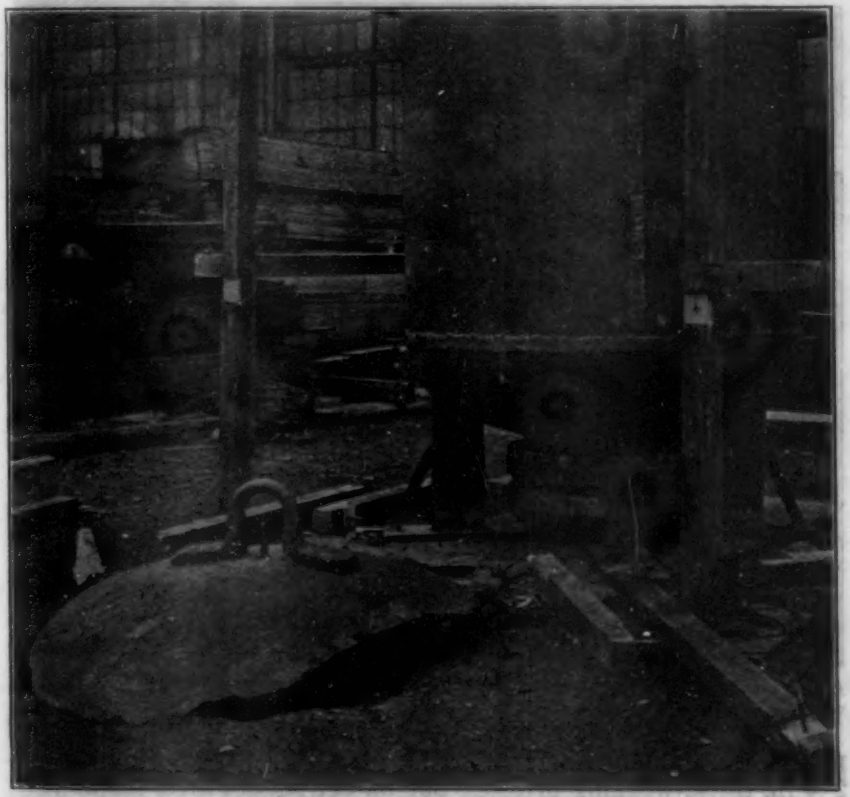

Fig. 4. View of lower portion of section tested. The head construction shown illustrates the type of steel head used in the construction of these stills. The section of the cast steel head that was welded on top for test purposes and blown off during the test is shown in the lower left hand corner.

Extracts from letters of C. C. Joys of the A. O. Smith Corporation, dated July 31 *and Aug.* 27, 1925:

The welding of the test vessel referred to in Bursting Test Report of April 28 was welded by our Patented Electric Arc Welding Process. This process is absolutely automatic in every way and with its use it is impossible to burn the steel adjacent to the weld. The speed of the arcs is controlled by a master head which is set for the thickness of metal to be welded.

The chemical properties of the plates in this vessel were: carbon .20-.30, sulphur under .04, manganese .40-.60, phosphorus under .04.

The only preparation of the material before welding was the grooving of the edges of these plates to suit our method, which is, in a way, very important. The fact that the groove is not filled in but the metal adjacent to the groove becomes a part of the weld by the fusion which takes place makes it necessary that preparation of the edges be very exacting.

Fig. 5. Manufacturing Oil Field Casing Couplings.

The vessels we are making for this purpose for one of the large producing companies will be 41 ft. overall, 5 ft. inside diameter, 2½ in. thick, working pressure 500 lb. per square inch, inside temperature 950 deg. F., outside temperature 1500 deg. F.

Under the conditions that these vessels have to operate and which we have noted above, you will note that it would be necessary that we know the action of the weld and the parent metal at elevated temperatures. In order to ascertain this information we, as you know, made hundreds of tests of this nature, the results of which were very gratifying.

We are also manufacturers of Oil Field Casing Couplings. These have to stand terrific abuse in the field operations and we have made approximately one-half million of these without a single complaint in the field, so we are attaching a photograph of the welding department for this work. (Fig. 5.)

Arc Welding as a Manufacturing Process*

H. M. HOBART† AND W. SPRARAGEN††

The arc weld is a very recent addition to the commercial tools available in manufacturing. To a considerable degree its rather wide applications may be said to have come about as a by-product of the war. Delays in replacing broken, worn and defective castings and other parts employed in their products or in the machinery of their systems forced upon industrial managers, railroad executives and others the necessity of repairing such parts by welding. The intensive, successful use of arc welding in repair work led to the gradual adoption of the process in manufacturing work as a substitute for riveting where parts have to be fabricated.

It is not the intention of the authors to cover in this paper applications of arc welding in the repair field or to discuss the economic advantages resulting from applications in this field. The American Bureau of Welding (which is the research department of the American Welding Society), hopes to shortly undertake a comprehensive investigation of the applications of welding and of its possibilities in the erecting of structures, bridges, buildings, etc. In order to assist this work the authors hope, through a review of some of the more prominent applications of arc welding in manufacturing processes, to bring to the attention of engineers, designers and legislators the possibilities of arc welding and the advantages which may result from its use. The inclusion in this paper of many examples of applications of arc welding in the manufacturing field has been made possible through the courtesy of the General Electric Company and the Westinghouse Electric and Manufacturing Company. These numerous applications of welding have been brought about through economic reasons, among which may be listed (1) lower cost of the product, (2) increase of production, (3) improvement in the quality of the product and (4) the overcoming of manufacturing and other difficulties. In fact, each application listed in this paper illustrates one or more of these reasons.

Manufacturers who contemplate introducing arc welding into their shops as a fabricating means, must give attention to several fundamental considerations. Of these fundamental considerations, the more important will now be stated.

Design

Structures and parts of products which it is intended to weld by the arc process, must of course be properly designed to conform with the technique of arc welding in order that they shall effectively withstand the stresses which they will meet in service.

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*To be presented at Fall Meeting of A.W.S. in Boston, October, 1925.

†Chairman, Electric Arc Welding Committee, A. B. W.

††Secretary, Electric Arc Welding Committee, A. B. W.

It is a wrong basic principle to simply substitute arc welding for riveting in a structure originally designed for riveting. While such a course can sometimes be justified as a temporary expedient, it is not fair to arc welding to judge it from results obtained in such cases. The product in whose manufacture arc welding processes are to be employed, should be designed with full recognition of this circumstance.

As an example of the need for special designs which recognize the fundamentally different basis of the two methods of joining metals it may be noted that whereas for riveted joints it is necessary to overlap the plates or employ straps, the use of arc welding often permits butt joints to be used. This effects a considerable saving beyond that which could be made by retaining the overlap necessary with riveting.

The material employed should preferably be such as is known to be most satisfactorily arc welded. Thus while arc welding is often applicable to joining cast iron parts, the art has not yet been so highly developed for such a purpose as for welding mild steel. Experience is being rapidly gained in applying the arc welding process not only to high carbon steel and to cast iron, but even to special ferrous alloys and to non-ferrous metals. But the great mass of the most important and satisfactory applications relates to joining mild steel parts, such as steel castings, steel plates and rolled structural steel.

Adequate care should be taken in determining allowable stresses for the welded joints. In the past, designing engineers who were not familiar with arc welding have been apt to base their determination of the required cross-sectional area of some particular weld on some general limiting value for the tensile strength or shearing strength in pounds per square inch. There are quite a number of important variables which must be taken into consideration, such as for example, (1) the design of the joint, (2) the chemical composition of the material to be welded, (3) the type of electrode used, (4) the position in which the weld must be made, (5) the general experience of the welder and (6) the experience of the welder in that particular kind of job.

A steel weld is a steel casting and it is well known that a steel casting will not withstand bending stresses to any such extent as a steel forging of the same tensile strength. This indicates that in service, arc welds withstand tension stresses best. Their ability to withstand shearing stresses comes next in order. The detailed preparation of the parts prior to welding is also very important. The angle of bevel should be suitably proportioned and the surfaces should be free from oil, scale or rust. It is generally desirable to provide suitably designed jigs or fixtures to hold the pieces in line and in the right plane while being welded.

With a good mild steel welding wire such as is described below and with plate having an ultimate tensile strength of 55,000

lb., the tensile strength of an arc weld made with a reasonably skilled operator may be taken as 40,000 lb. per sq. in. of weld section. The weld section can usually with advantage be made 10 per cent to 20 per cent greater than the plate section. For fiber stresses in pressure vessels, the safe working stress for arc-welded joints may be taken as about 8000 lb. per sq. in. of the plate section.

The shearing strength of welds may be taken as 36,000 lb. per sq. in. For structural steel work a factor of safety of 4 is suitable. This makes the working tensile stress of arc welds in structural steel 10,000 lb. per sq. in. and the working shearing stress 9000 lb. per sq. in.

Of course, a highly skilled welding operator, even with the materials mentioned, may obtain welds as strong as the original material itself and with special electrodes can produce an arc weld which will break the plate every time. Although at present there does not exist a great deal of data as to the fatigue strength of weld metal, a few tests that have been conducted indicate that one-half of the ultimate tensile strength may be employed as an ultimate endurance limit below which an arc weld will not break for millions of cycles of repetitions of stresses.

Material

In addition to chemical requirements, there are other properties in steel which are important from a welding viewpoint. As regards its physical properties, well-made steel is largely dependent upon the amount of carbon in it. This is the first thing to be considered in deciding what chemical analysis should be followed. Other things being equal, the higher the carbon the more difficult is the welding and the less satisfactory is the weld. Of course, the difference in welding qualities is not of much consequence between 0.10 per cent and 0.20 per cent carbon, but there is usually a marked difference when the carbon content exceeds 0.20 per cent. In arc welding, there is localized heating which affects the high-carbon plate to a greater degree than the low-carbon plate. In plates above 0.20 carbon there is apt to be a hard brittle zone next to the weld. Moreover, in arc welds with low-carbon material, the rigidity of the welded joint transfers any bending or vibratory stresses to the parent plate outside of the weld and this is more capable of withstanding such stresses. But in high-carbon material the bending and vibratory stresses will not be so effectively diverted from the welded joint to the parent plate.

Welding Rods

Good welding wire, in so far as chemical composition is concerned, may be ensured by following the American Welding Society specifications for welding wire given in its Bulletin No. 2. Chemical composition, however, is not a complete criterion. For example, wide variations in the chemical composition of the deposit are obtained when welding wire of identically the same composition

is deposited in the weld by the electric arc process. The physical structure and the gas content appear to exert considerable influence on the result. However, the phenomena are still far from being understood. A simple test of welding wire additional to the chemical analysis can be made by laying a piece of welding wire on an iron table and melting it half way through with a gas welding torch. Good welding wire can be distinguished (1) by the ease and smoothness with which it melts, (2) by the evenness and smoothness of the melted surface and (3) by the lack of sparks. Wire that (1) sparks badly (has a rough porous surface after welding), or (2) does not flow freely and smoothly, is unsuitable for welding. A similar test may be made on the steel to be welded by running the torch flame so as to cut a depression in the steel. If the surface is rough and shows small blowholes it is an indication of unsuitability for welding.

Electric Current Test for Welding Wire

The melting test may also be conducted with electric welding apparatus by "freezing" one end of the electrode to the work or plate, using the normal welding current for the size of the wire involved. By keeping the wire in direct contact with the plate it will reach a uniform melting condition, but if the current is too high the wire will melt close to the plate only and not present sufficient melted surface for observation. It is, therefore, necessary to adjust the current so that the wire heats up slowly throughout its entire length.

Jigs and Fixtures

The application of arc welding as a fabricating process can in most instances be made more economical and successful through the use of suitable jigs and fixtures. For quantity production very thorough consideration should be given to this aspect of the process in order that full advantage may be taken of the economies in time and labor which may thus be rendered possible. This point is illustrated in a number of the applications of arc welding described in a later portion of this paper. As an example of a specific application, namely pipe welding, the reader is referred to pages 34 to 38 of the November, 1924, issue of the *Welding Engineer* and to pages 34 to 38 of the December, 1924, issue of the *Welding Engineer*.

Testing the Skill of Operators

With the proper control and assuming conscientiousness and reasonable skill, the quality of a given product is fairly independent of the operator. On the other hand, he must be experienced in depositing the metal in the way most appropriate for the particular job in hand. The expertness of the operator can in most cases only be tested by physical tests to destruction of

test specimens of the work which he is doing. Once the welder has proved himself competent to do a particular job, it rests upon the supervisory and inspecting force to see that the quality of his work is maintained.

On the other hand, great pains should be taken not to destroy the initiative of the welder. The welder should not be ignored if he complains about conditions not being right. His complaint should be carefully investigated, as sometimes materials which have been accepted by the purchasing department are nevertheless not suitable for the work in hand.

It should also be pointed out that while some welding operators can do a 100 per cent job on certain work, they are entirely unfitted for other kinds of work where it is not apparent that any greater skill is necessary. For example, a man who through long experience can weld thin steel in a flat position may not be able to do it in an overhead position. Again, he may not be able to weld thick steel plates even in a flat position. In another instance a welder who is an expert on repair work may be entirely unsuitable, without additional training, for production work on steel.

Many experts in the welding field recommend periodical tests of sample welds to check the skill of their welding operators. Where facilities for testing welded samples are not available, local arrangements may be made with a commercial laboratory on a reasonable basis. The testing should be done on the kind of work which the operator is performing. At the request of the authors, the Electrical Testing Laboratories of New York state as follows:

> "Our regular charges for tensile tests of prepared specimens are $5.00 for the first specimen, $3.50 for the second and $3.00 for the third when all specimens are submitted at the same time. This includes the determination of the breaking load and tensile strength in pounds per square inch, the yield point in pounds per square inch, the total elongation and reduction in area. The regular charges for a bending test are $3.00 for the first specimen, $2.50 for the second and $2.00 for the third when three specimens are submitted at the same time. This includes the determination of the angle and load at first crack and the maximum load and angle at complete rupture."
>
> "We would be glad to quote special rates for these tests as follows:

	3 Per Month	12 Per Month
Tension test	$3.00 each	$2.50 each
Bending test	2.00 each	1.50 each

This illustrates that it is possible to make arrangements with some local organization to do the testing on a regular basis and at reasonable cost.

Inspection

Inspection of welded products must differ somewhat according to the nature of the work involved. Certain fundamental principles can, however, be laid down as universally applicable in arc welding.

The importance of proper inspection and supervision cannot be over-emphasized. Almost every article and book written on welding prior to the last few years, directly or indirectly has im-

plied that the quality of the product was 90 per cent dependent on the skill of the welding operator. With the methods generally in vogue up to the last two or three years this statement was probably fairly correct, as in most cases the selection of material, the design and the technique of the work were left to a considerable extent to the welding operator. Under these circumstances, it would have been even more correct to state that the quality of the job was 100 per cent dependent on the welding operator. When the problems of material, design and technique are worked out in advance, the welding operator is only called upon to manipulate the electrode to do a particular job. When relieved of these other responsibilities the welding operator can, after a little training, be depended upon to do the work day in and day out with less percentage of variation in quality than is found in riveting. This, of course, presupposes the existence of a competent inspecting and supervisory force.

This supervising and inspection service should include:

1. The provision of suitably designed and constructed jigs and fittings.
2. Checking whether all the requirements as to preparation before welding are fulfilled.
3. Whether suitable materials are being used.
4. Checking the method of deposit of the metal.
5. Whether the right current is being used.
6. Whether the right size of welding wire is being used.
7. Whether the actual manipulation of the electrode is satisfactory.
8. Whether the parts to be welded are clean and free from foreign matter.
9. Whether the proper penetration and fusion are being obtained.

In some cases it might be desirable to have the welding operator stamp his number on the job, and in still others the inspecting force might test parts of the work to destruction.

Testing the Finished Product

The greatest handicap to welding is stated by many authors to be that we have no satisfactory non-destructive test available to check the quality of the weld. Many conservative engineers argue that after a job is finished it is impossible to know with certainty whether it is a 50 per cent or 100 per cent strength weld. Proponents of welding in turn answer that it is equally impossible to know the strength and quality of a finished riveted joint, the only difference being that we have grown accustomed to be satisfied with a visual inspection of a riveted joint instead of requiring a test to destruction. This is because riveting has been with us for a long period, the processes have become standardized and we have learned from experience to place confidence in the product.

This same psychological process is taking place with arc welding. However, whereas the riveting art has been practised for centuries,

we have only been using arc welding extensively for a matter of seven or eight years.

As implied indirectly in previous statements it should be pointed out that the quality of the finished job can be determined in advance, if proper material is used and proper design and technique employed and if there is in force a system of regularly checking the skill of the welding operator as to his ability in manipulating the arc.

The most suitable ways of testing welds and welded products are different for every industry. They depend upon the nature of the particular problem in hand. In some cases hydrostatic pressure can be applied with an intensity sufficient to allow a reasonable margin over the stresses that the particular product will meet in service. Penetration of oil, or bubbles from a soap solution, reduction of air pressure and blows with a hammer are also useful tests for certain classes of work. But in the great majority of cases tests of this sort are neither possible nor desirable.

Cost Data

A great deal of information now exists on the subject of cost of electric arc welding and in a number of industries comparisons between riveting and arc welding are available. As pointed out in the introductory remarks, a later portion of this paper will be devoted to examples of applications of arc welding and comparisons as to the relative cost and quality of product with previous forms of fabrication, such as riveting. In one industry, namely, the shipbuilding industry, considerable information exists and has been published by the American Welding Society. This information is embodied in a report by Mr. E. H. Ewertz entitled, "Applications of Arc Welding to Ship Construction," which was published as Bulletin No. 6 of the Society. This Bulletin contains tables and charts worked out in detail which enable draftsmen and engineers to readily compute the cost of doing a particular job. Similar charts based upon experience should be worked out for other industries. Mr. Ewertz, who is a leading authority in shipbuilding, estimates that in the construction of a ship's fittings and in hull construction, savings ranging from 15 per cent to 25 per cent may be effected. The application of welding to ship's fittings is already extensive. But the conservatism of shipbuilding concerns has restricted the use of welding in joining the hull plates, to a few small vessels all made by different firms and the cost of these first applications has, of course, always been high.

Speed of Arc Welding

The data given in various text books and papers as to the speed of arc welding are very conflicting. There are so many variables as to make any general statement impossible. The following review will throw light on the matter:

There are automatic arc welding machines which make long seams at several times the speed possible with hand welding. From the data at present available the speed of making such seams in thick plates (say ½ in. thick) is two or three times as great with an automatic machine as with hand welding. With thin material (say ⅛ in. thick) the speed with the automatic machine is from five to ten times as great as by hand. Hand operators lose time in changing electrodes and in adjustments of position. Moreover, the hand operator becomes fatigued while the automatic machine can keep right on.

Material up to and including ¼ in. thick is being successfully butt welded unbevelled on automatic machines. It is not generally realized that the angle of bevel greatly affects the speed. The authors once conducted a series of tests on the hand welding of ½ in. thick ship plate. Among many other experiments made in the course of these tests, four samples of butt welds each 3 ft. long were welded by the same operator. The total angle of opening formed by the bevel on the plates being welded in the four cases were 30 deg., 60 deg., 90 deg. and 120 deg. respectively. The welder deposited metal at about 1.75 lb. per hour in all cases. But it took so much more metal to fill up the 120 deg. bevel as to reduce the speed of welding to only 1.07 ft. per hour as against 3.22 ft. per hour for the 30 deg. bevel. Much interesting data of this investigation are given in a table at page 1955 of Pender's "Handbook for Electrical Engineers."

It is interesting to note that for all four bevels in the above investigation, the rate of deposition of electrode was a matter of 0.65 lb. per kw. hr. at the arc on the basis of a 20 volt drop at the arc. One kw. hr. is equal to 860,000 calories; 136,000 calories will melt a pound of mild steel. Therefore if all the energy in the arc had been used up in melting electrode material, 6.3 lb. ought to have been melted per kw. hr. at the arc, i.e., about ten times the amount actually melted. But part of the energy in the arc is required to heat and melt the surface layers of the parts to be joined; part may vaporize some of the steel and part is lost in conduction, radiation and convection. Even at this late period in the development of arc welding there has not been made enough advanced physical research of the fundamental phenomena to even approximately allocate the 90 per cent of energy not consumed in melting the welding wire.

It seems to us that very exaggerated ideas are prevalent as to the amount of metal which can, in practical high-grade work, be deposited per hour in the arc welding process. Some years ago one of us published the statement that for hand welding an operator can in the case of the hull plates of ships deposit about 1.2 lb. of metal per hour when working out in the open (as on ships) amidst many inconveniences, as against about 1.8 lb. per hour in the shop. From the General Electric Company's report in this paper it can be seen that based on the average for a month for all

sorts of work the rate of consumption of electrodes was 1 lb. per welding operator per hour. This would probably correspond to nearly 2 lb. during actual welding. In melting 13,500 lb. of welding wire some 36,000 kw. hr. were consumed, or 0.375 lb. per kw. hr. But this very probably corresponded to some 0.6 to 0.7 lb. per kw. hr. *at the arc.*

As an experiment, a 12-ft. cube tank of ½ in. thick steel was, in 1918, arc-welded. The total time of actual welding was 165 hours, and this corresponded to using up electrodes at the rate of just 2 lb. per hour. The energy consumed at the arc was about 500 kw. hr., and 334 lb. of welding wire was used up, of which 299 lb. was deposited in the welds. There was thus deposited 0.60 lb. per kw. hr. of energy at the arc. In making this estimate it has been assumed that the current was 167 amperes and that the pressure across the arc was 20 volts.

In a paper entitled "Welding Mild Steel," written by one of us in 1919, the following view, with which we now fully agree, was expressed:

"The practice heretofore customary of stating the speed of welding in feet per hour has led to endless confusion as it depends on type of joint, height of weld and various details. A much better basis is to express the speed of welding in pounds of metal deposited per hour. Data for the pounds of metal deposited per hour are gradually becoming quite definite. The pounds of metal per foot of weld required to be deposited can be readily calculated from the drawings or specifications. With the further available knowledge of the average waste in electrode ends and from other causes, the required amount of electrode material for a given job can be estimated."

For overhead welding or for welding in difficult places, the speed of deposition is much lower than the above value of from 1 lb. to 2 lb. per hour. This is also true when, instead of mild steel, some other material is to be joined.

We have seen records of butt welding with automatic machines where long seams in ⅜-in. and ½-in. plates have been welded at 15 ft. and 12½ ft. per hr, with a consumption of 6½ lb. of welding wire per hour. The angle of bevel was 30 deg. and the current from 250 to 300 amp. It is, however, more usual for automatic welding of butt seams in ½-in. plate to estimate on speeds of only from 4 to 8 ft. per hr. of actual welding, as against somewhat under half these speeds for hand welding.

Very high speeds are obtained when arc welding quite thin material on the automatic machine. The precise values vary with the size of electrode and with the current. As an interesting example of an attempt to study the influence of the current, the following table of results obtained in butt welding 14 gage (0.078 in, thick) material is given below. The welding wire had a diameter of ⅛ in..

Current in amperes	Volts at arc	Speed of welding in feet per hour
165	15	110
195	16	135
200	18	180
220	18	200

In a book entitled "Arc Welding and Cutting Manual," published by the General Electric Company in 1924, the following table of values is given, accompanied by the statement that "these figures are actual welding speeds and will be modified on production work by idle time, preparation, etc."

RATE OF TRAVEL (BARE METALLIC ELECTRODE)

Thickness of Plate in Inches	Feet Per Hour (Butt Weld) Hand Welding	Semi-Automatic Welding	Full-Automatic Welding
1/16	10	20 to 40	75 to 150
1/8	7½	15 to 30	40 to 75
3/16	6¼	12 to 24	25 to 50
¼	5	8 to 16	15 to 40
3/8	2½	5 to 10	6 to 12
½	2	2½ to 5	3½ to 7
¾	1¼	1¾ to 3½	2½ to 5

The following tables of speeds are recommended by the authors for estimates on the arc welding by hand of mild steel:

Thickness of Plates in.	Size of Electrodoes Diameter in.	Approximate Current Amperes	Pounds Deposited Per hour
1/8	1/8	100	1.4
¼	5/32	150	1.7
3/8	5/32	160	1.8
3/8	7/32	200	2.2
½	5/32	175	2.0
½	7/32	225	2.4

The above speeds are such as can be maintained by a fairly skilled welder during an eight hour day and under favorable conditions such as welding in the shop. The plates to be welded are assumed to be laid flat and at a convenient height for the operator to work. It is also assumed that the edges have been prepared and the plates clamped, all ready for welding. For vertical welding these figures should be multiplied by 0.9. For overhead welding they should be multiplied by 0.7. For work in the field, where the arc is not protected and the welder subjected to inconveniences, all these figures should be multiplied by 0.7.

EXAMPLES OF ARC WELDING APPLICATIONS

Locomotive Boilers and Other Motion Parts

Arc welding of tubes in boilers is standard practice on several large railroads. The length of service of locomotive boilers before leakage commences is thereby increased from three or four months to three or four years. (Details of the application of arc welding in locomotive boilers is given on pages 35 to 38 of the March, 1922, issue of the JOURNAL OF THE AMERICAN WELD-

ING SOCIETY.) (See also pages 687 to 697, October, 1924, issue, of the *General Electric Review.*

Welding Pipe Lines for (1) *Oil,* (2) *Gas,* (3) *Water,* (4) *Steam,* (5) *Dredging*

A permanent non-leak joint may be obtained by the use of arc welding on pipe lines. A cheaper and better job is secured in all sizes of pipe lines by the use of welding. Miles and miles of welded pipes, varying from small diameter to very large diameter and from very low to very high pressures have been successfully arc welded. They have given satisfaction in service and in a number of instances a saving as high as 25 per cent may be effected over the screwed or flanged joints. Angles, ells, tees and other fittings may be economically welded. Several articles have been published on this subject in the *Welding Engineer* and the JOURNAL OF THE AMERICAN WELDING SOCIETY. At pages 21 to 28 of the April, 1922, issue of the JOURNAL OF THE AMERICAN WELDING SOCIETY is an interesting paper by J. H. Nead and R. L. Kenyon entitled "Applications and Tests of Large Diameter Electric Welded Pipe." Further information may be obtained from page 19, September, 1923, issue, *Welding Engineer.*

Well Casings

Oil well casings have been constructed for oil fields of Southern California. The electric arc has proved its efficiency in the handling of large sections and in simplicity and economical production methods. The particular casings were 13 in. in diameter and made of No. 10 gage iron. It is two ply and built in 30 ft. sections, each section consisting ten three-foot lengths. For details see April, 1924, issue, *Welding Engineer.*

Rail Joints in Street Railway Tracks

Nearly all joints in tracks in paved streets are now made by some process of welding. The electric arc is used extensively in this work. The Welded Rail Joint Committee of the American Bureau of Welding is at the present time devoting attention to possible improvement in making the seam welded type of rail joints. An improvement of 25 per cent in the life of the joint, which is confidently expected by the committee, will result in a saving of millions of dollars annually to the street railways of the country. For further information reference should be made to Progress Reports Nos. 2 and 3 of that committee.

Storage Tanks

A number of small and large storage tanks for holding oil, water and gas have been completely constructed by electric arc welding. In other cases tops and bottoms only have been welded. Literally thousands of welded tanks have been constructed in various parts of the world, varying in size from a few gallons to

gas holders of 2,000,000 cu. ft. capacity, 200 ft. in diameter and 130 ft. high. Full descriptions of methods of construction used in the larger tanks are reported in the various issues of the JOURNAL OF THE AMERICAN WELDING SOCIETY and in the *Welding Engineer*. Not only have there been substantial savings in the construction cost (from 10 to 25 per cent), but still larger savings in tanks for holding oils and gases. The welded construction reduces to a minimum evaporation and leakage. For lighter oils this saving is an appreciable item as compared to the leakage and evaporation from a riveted tank and may equal in a very few years the total cost of the welded tank. A report of the American Bureau of Welding's Committee for the Electric Welding of Storage Tanks is given at pages 16 to 19 of the December, 1922, issue of the JOURNAL OF THE AMERICAN WELDING SOCIETY. For further information on the applications of arc welding in this field, the reader is referred to the following issues of the JOURNAL OF THE AMERICAN WELDING SOCIETY: October, 1922, pages 25-26; August, 1923, pages 14-24; June, 1924, pages 11-21, and to the following issues of the *Welding Engineer:* May, 1923, pages 25-29; September, 1923, pages 25-28; September, 1924, pages 32-38, and June 1925, page 29.

Ship Construction

Allusion has already been made to the great field for arc welding, not only in the fittings of ships, but in joining the hull plates. For the fittings of ships the use of arc welding is increasing rapidly. But as a method of joining the hull plates the only applications have been to a few relatively unimportant ships, a list of which is given at page 83 of this paper. Although the plan of using arc welding instead of riveting for joining the hull plates of ships has been reported upon favorably many times by men of unquestioned authority, wide experience and mature judgment, the use of riveting for this purpose appears to be so strongly entrenched that it will not be likely to be replaced by welding on any considerable scale until those at present in control of the shipbuilding industry have been succeeded by younger and more enterprising and open-minded men. For oil tankers there is with arc welded hulls the additional advantage of oil tightness. But for steel hulls for any purposes it is hard to realize that unreasoning determination to oppose any change can hold out in the face of the certain advantages in (1) saving of material, (2) saving of labor and (3) increased seaworthiness.

There are several classification organizations such as Lloyd's Register of Shipping, and the American Bureau of Shipping, which have published lists of items in ship construction where arc welding may be employed without obtaining special authorization from the approving and inspecting organization.

A good many minor and non-structural items and important fittings in merchant vessels, destroyers and submarines are now

regularly arc welded. The following are examples of applications in this field:

1. Important FITTINGS, such as continuous railing rods, skylights, stairs, gratings, ladders, coal chutes, ventilator cowls, stacks, funnels, uptakes, bulkheads (which are not structural parts of the ship), tanks, hand rails, deck houses not covering unprotected openings through weather decks, battery and storage boxes, trap seating, holders for boiler spare parts, drip pans, conning tower hatches, ventilation and exhaust pipes, torpedo doors, periscopes and ammunition scuttles.

2. Minor items, such as lashing pads for torpedo tubes on deck, boat chocks on davits, sockets for hand rails, cable and fixture hangers, cable guards, bucket stowage, pipe supports, berth supports to frames, pipe hangers, leaders on deck for steering cable, chocks under turbines and gear cases, hangers for operating rods, pads for all purposes, bars on escape hatches, cargo batten cleats, protecting angles around manholes, seatings for fire extinguishers, brackets, waterway bars.

3. CLIPS for jack rods on galley house, ram rods, stanchions, work benches, battery lockers, stores for paints, oils, provisions, electric, galley, torpedo and magazines, oil burner rack, oil racks, transoms, gage boards, lathe and grinding stones, ladders, engine room flooring supports, table, cable hangers, bulkheads, detachable rail stanchions, shelving, lockers.

4. FOUNDATIONS and SUPPORTS for oscillator, bulkheads, battery hatch, torpedo slides, guns, starting flasks, switchboards, engine and boiler room floorings, discharge manifolds, oil tanks, wash machines, compass, diving and steering gears.

5. ATTACHING deck rail stanchions to plating, deck collars around ventilators and funnels, cape rings, galley fixture to plating, bath and other fixtures, cowl supporting rings, engine and boiler room stairs and gratings to plating, cleating to casing, door frames to casings, airtight shoes to bulkhead.

The authors have records of seven electrically welded ships. These may be briefly mentioned as follows:

I—1915—The Dorothea M. Geary, 42 ft. long and 11 ft. beam, was launched on Lake Erie. The hull plating was butt welded by the electric arc process.

II—1918—British Admiralty's cross-channel barge Ac1320, 125 ft. long and 16 ft. beam and of 200 tons deadweight, was completely arc welded.

III—1919—At Caen in France a barge 65 ft. long by 13 ft. beam was arc welded. The welding was all done by women.

IV—1920—The Fullagar, a 500-ton coaster of 150 ft. length, built by Messrs. Cammell, Laird & Co., was launched at Birkenhead. The hull plates were joined entirely by arc welding.

V—1920—At Gothenberg in Sweden, a tug boat of 52½ ft. length and 13½ ft. beam was arc welded.

VI—1920—The Sea Hornet was launched from the shipyard of Kyle and Purdy, City Island, New York, N. Y. She is a motor boat 58 ft. long with a 600 hp. engine and has a speed of 35 knots and a cruising radius of 800 miles. Electric arc welding was used throughout for all joints. Butt welding was used throughout the shell, this having the advantage of providing a smooth surface and decreasing the hull friction.

VII—1924—At Providence, R. I., was built and launched an oil barge 76 ft. long, 21 ft. wide and 11 ft. in depth. Electric arc welding was used for all joints.

These seven ships are all, so far as the authors have learned, still giving satisfactory service. Interesting particulars of several of them are given in Mr. E. H. Ewertz' paper entitled, "Applications of Arc Welding to Ship Construction," which is Bulletin No. 6 of the American Welding Society.

Mention should also be made of the attachment, by arc welding, of anti-submarine bulges to the hulls of battleships. The shell plates of these bulges were also joined by arc welding. The construction of such bulges involves more feet of welding and the use of thicker plates than the hulls of fair sized ships.

Arc welding of practically all joints was used in a steel self-floating caisson for a 460-ft. dry dock at the Hikoshuma Dockyard. Another Japanese enterprise was the arc welding at the Kobe plant of a floating crane pontoon 65 ft. long and 35 ft. beam.

At the Norfolk Navy Yard a battle towing target 172 ft. in length was completely arc welded in 1920.

Several ships of considerable size have had portions of their hulls arc welded with a view to gaining experience. Amongst these may be mentioned the conversion of the steam trawler Dairyo Maru into a 300-ton deadweight oil lighter in 1920, and the Hisco, a 1200-ton oil barge in which 60 ft. of the midship section was arc welded. Further particulars of these undertakings are given in the report of Mr. Ewertz to which reference has already been made.

Arc Welding in the Construction of Steel Buildings

The most recent example of this type of construction is given by Mr. A. G. Bissel of the Westinghouse Company, in an article entitled, "Arc Welded Steel Building," on page 17 of the May, 1925, *Welding Engineer*. The article describes a 40 ft. by 60 ft. mill-type building designed and built by the engineer of buildings of the Chicago, Burlington and Quincy Railroad. The building was constructed of scrap structural steel. Many of the steel pieces used were heavier than necessary, but they were used simply because they were available in the scrap pile and not because any additional size was necessary over the same joint riveted. The saving in the cost of building this structure by arc welding was

41 per cent of the cost of a riveted structure. Fig. 1 shows interesting details.

Architects have not yet acquired sufficient confidence in the arc welding process as a means of fabrication to adopt it for large buildings. Also, from what has been said in the first part of this paper, it will be understood that a competent supervisory force

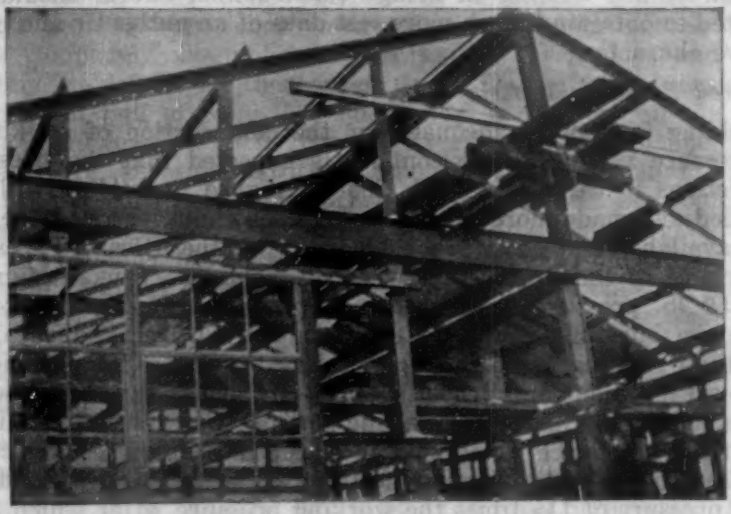

Fig. 1. Completely Arc Welded Building Built by the C.B. and Q.R.R. for a reclamation plant at Eola, Ill. Scrap Material was used, hence the rivet holes.

must be available in addition to the welding crew. There is undoubtedly necessary a new type of technical training, namely, welding engineering, and perhaps one good way to advance welding would be to interest various engineering schools to teach welding as a science in addition to the present instruction in structural engineering. However, before taking this step the theory and practice of welding design must be thoroughly worked out.

Other examples of welded buildings are given in the paper by Messrs. Goldmark, Spraragen and Warner in the October, 1924, JOURNAL OF THE AMERICAN WELDING SOCIETY.

Arc Welding in Bridge Construction

Actual examples of welded bridge construction are few, but the possibilities are many, as was pointed out in the paper to which reference has just been made.

The Iron Age of May 25, 1922, printed an article by E. S. Humphreys, giving some test data of welded structural steel. In the February, 1922, JOURNAL OF THE AMERICAN WELDING SOCIETY, Prof. F. P. McKibben summarized these test data and explained a method of design of a welded structural joint.

The most recent example of a welded repair job of a bridge is that described on page 45 of the August, 1925 *Welding Engineer*.

The bridge in question is located at Paris, France, and was of an arched construction of cast iron. The repair was successfully completed by electric arc welding.

However, the riveting process as applied to bridge construction is very firmly established and riveting methods are thoroughly standardized. In order to make effective headway with the introduction of arc welding in bridge construction, efforts should be directed to obtaining much more test data of an authentic and conclusive character.

Un-fired Pressure Vessels

Welding is entirely adequate for the construction of all kinds of pressure vessels. It is confidently expected that the present restrictions in the A. S. M. E. Code in regard to welding will be modified and made more liberal, based upon the scientific evidence now available and soon to be obtained by the Pressure Vessel Committee of the American Bureau of Welding. Tanks designed for 250 lb. pressure have withstood pressures as high as 2400 lb. before bursting. Welding can produce a better and cheaper tank than riveting when properly designed and constructed under approved technique and proper supervision. The test recommended by the American Bureau of Welding for pressure vessels is indicative of the confidence which may be placed in properly constructed vessels. This test calls for hammering a tank when under a hydrostatic pressure of 1½ times the working pressure, after which the pressure is to be raised to three times the working pressure and held there three minutes except in the case of vessels of special construction such as shell and tube brine coolers, condensers, intercoolers, etc., in which case the pressure shall be raised to two times the working pressure. This may be compared with the hydrostatic test of 1½ times the working pressure required by the A. S. M. E. Boiler Code for riveted vessels.

A $100,000 investigational program is to be undertaken shortly by the American Bureau of Welding. Those desiring to cooperate in this work should communicate with the secretary of the American Bureau of Welding.

Fired Pressure Vessels

Many types of steam and hot water boilers and fired pressure vessels for various industrial purposes ranging from low pressure to high pressures and high temperatures are now in successful use.

As an illustration of what may be done by welding there is cited the gasoline cracking still manufactured by the A. O. Smith Corporation. This still made of 2½ in. thick plates, is 41 ft. in length, 5 ft. inside diameter, 500 lb. per sq. in. working pressure, temperature inside 950 deg. Fahr., temperature of furnace 1500 deg. Fahr. On test one of these stills withstood a hydrostatic pressure of 4700 lb. per sq. inch without affecting the welds. Of course, the manufacture of a product of this nature requires ex-

pert knowledge of welding including physical phenomena, materials, metallurgy, design, and heat effects on steel.

Arc Welded Radio Towers.

In the September, 1922, issue of the *Welding Engineer*, Mr. H. S. Bear describes two welded radio towers 150 ft. high, largely made of steel pipe, which were built in 1921 at Peking, China. The welding was done entirely by unskilled Chinese labor. After gaining experience on the first tower, the second tower was completely assembled in position in seven days and completely welded in another seven days. The antenna occasions a horizontal pull of 3000 lb. The tower is designed on the basis of a wind load of 25 lb. per sq. ft. of projection in one plane. There are several distinct advantages to be found in the design and construction of such towers. Members are round and offer relatively small resistance to wind. Pipe sections give nearly perfect columns, having the greatest strength possible with a given amount of metal. Short end pipes are all used up in the construction. Arc welding is much cheaper, quicker and easier than riveting. Use of material of light weight permits easy erection of long shop sections. The finished tower has smooth, easy lines and offers a pleasing appearance.

Electric Transmission Line Towers.

In an article at page 88 of *Engineering*, January 20, 1922, the title of which is "Electric Arc Welding in Steel Structures," Major James Caldwell calls attention to the particular applicability of arc welding in the construction of poles and masts of the lattice type. He states that there is at present a good demand for these lattice masts for the support of electric transmission lines and radio aerials. In Major Caldwell's article is illustrated one of the 500 transmission line posts which at that time had been recently constructed in Belgium. These posts are 72 ft. long overall, 5 ft. of this length being imbedded. They are built to carry two three-phase lines and a guard wire, making altogether seven wires on spans of 525 ft. The stress due to the pull of the wires with a maximum wind blowing across the line is calculated to amount to 1350 lb. horizontal pull at the top of the post. A statement of the various dimensions is given in the article. These posts weigh ten per cent less than those riveted in the usual way. Major Caldwell states that two welders can complete these posts in nine hours' work, using about 45 kw. hours and 425 ft. of No. 10 electrodes.

One Hundred Foot Welded Tower.

This tower was completed in a cave in California and is built up of spiral strips of steel inclosing a spiral stairway. Every joint of the 7200 in the structure was welded by the electric arc. The cost of the completed tower was $3,000, as against the lowest estimate on the riveted structural steel tower of $12,000. The steel used in the welded tower was slightly over 3 tons. Similar weight

of a bolted and riveted structure is 13 tons. While not definitely stated in the article, the authors assume that the welded construction permitted the use of very much narrower strips for the entire structure as compared with riveting where a rivet hole constituted an appreciable part of the section of the strip.

Steel Floor.

An all-welded steel floor was constructed by the Hershey Chocolate Co., 64 ft. x 24 ft., for their milk receiving room. Heretofore cement and bituminous flooring were used with more or less leaking and a great tendency to crack. Three hundred thousand pounds of milk enter this room daily, mostly in 100 lb. cans. The plates were cut 4 ft. x 10 ft. x 3/8 in., planed to a 45 deg. bevel. The floor had to be 100 per cent waterproof and have as great a resistance to shock and abrasion as possible. With this type of construction it was possible to slide cans over a smooth surface, netting a saving on labor alone of about $1,200 annually.

Impact Pulverizers

Raymond Brothers Impact Pulverizer Co. of Chicago manufactures a system consisting of a grinding mill and pulverizer, an air separator exhaust fan, cyclone collector, a tubular dust collector and the necessary connecting pipes. Construction of one of these mills necessitates the use of a wide range of thicknesses of sheet metal and a great variety of joint design. Tops for air separators, return air housings, fan housings, etc., are all welded. As a result of the applications of welding, the finished product is more economical and stands up better in service than riveted joints. Moreover, they are absolutely dust tight. A considerable saving is also effected in the designing room, particularly in the matter of drawings, which is a considerable part of the total cost of such a structure.

Stacks for Buildings

The Boom Boiler & Welding Co. produces both riveted and welded stacks. They state, however, that a rapidly increasing number of owners are demanding the welded product. Considering the efficiency of joints in a stack, welded construction gives 100 per cent as compared to 60 per cent in the riveted types. Breachings and gas and smoke conductors in a stack generally allow leakage when riveted, which spoils the vacuum, hence handicaps the draft. Of course, when these parts of the stack are welded, the joint is 100 per cent air tight. Joints of a stack that must be subjected to heat strains can be held tight when welded, where they will give if riveted. Moreover, a welded stack has no rivet heads or rough edges to collect soot and soft coal, which form sulphuric acid and eat into the stack.

Steel Flasks

So successful has been the aplication of arc welding to the building of steel flasks, specially formed shells used in making sand

molds in foundries, that one of the largest producers of these has entirely discontinued the manufacturing of the cast or riveted product in favor of the welded steel flasks.

The arc welded flasks afford decided advantages over other styles, engineers report. Because the electric welding makes the sections practically one piece, the flasks are given greater strength and rigidity. The welded steel products also eliminate all annoyance caused by pieces coming apart as is apt to be the case with flasks bolted or riveted.

The flasks are made in a wide range of sizes from the small bench work styles up to the large, heavy duty sizes. The lighter weight flasks are built of 1/8 and 3/16 in. steel, while the larger and heavier ones are made from 1/4, 5/16 and 3/8 in. steel. The shells of welded steel construction are being made in practically any square or rectangular shapes. The cope or drag of the flasks ranges from 2 1/2 to 18 in. in depth, as desired.

Hess All-Welded Steel Furnace

Welding gives a leak proof, strong, rugged union which has brought this furnace into popular demand. All forms of welding are used in its construction. The welded, permanently tight construction of the furnace does not allow odor, fumes or smoke to escape. (For details see June, 1925, issue *Welding Engineer*.)

Locomotive Tender

A locomotive tender has been completely arc welded at the West Springfield shops of the Boston and Albany Railroad. The tender tank is 26 ft. long, 10 ft. wide, 5 ft. high and has a capacity for 8000 gallons of water and 12 tons of coal. At page 695 of the *General Electric Review* for October, 1924, Mr. W. M. B. Brady states that this tender tank "has now been in service for more than four years," being used with a Pacific type locomotive for passenger service. Arc welding is satisfactory for this work, as it can be done economically and with strength of joints in excess of that usually obtained from the riveted construction. Some 1200 ft. of welding are usually required on a tank of this sort.

Miscellaneous Applications

A very large number of rear axle housings are now built by using the automatic arc welding machine.

Water jackets may be formed economically of steel tubing and assembled by arc welding, using hand or automatic welding.

Radiator covers may be assembled very quickly and economically by welding light gage metal with either the metallic electrode hand operated or automatic arc welding machine.

Artistic baskets, guard rails and lawn rollers have been welded by the Cave Welding and Manufacturing Company on a production basis.

Silent chain drives are now enclosed in welded casings which keeps out dust, retains oil and increases the safety.

Attractive medicine cabinets for bath rooms are now entirely constructed by welding, using oxy-acetylene, electric arc and spot welding.

Ballast boxes are economically constructed by use of welding and are of a very rugged design.

A job welding shop in Oklahoma has proved that welding results in a stronger, neater and more satisfactory job for greasing racks and tank supports with a saving of approximately one-third on labor.

A sky scraper swimming pool was constructed on the twenty-first story of the Chicago Union League Club. Arc welding was used

Fig. 2. Various Sizes of Tanks Showing Arc Welding.

to insure absolute tightness. For further details see September, 1925, issue of *Welding Engineer*.

The Use of Arc Welding in the Factories of the General Electric Company

On behalf of the General Electric Company, Mr. M. A. Atuesta, chairman of the General Electric Company's Inter-Factory Welding Committee, reports as follows:

"Arc welding has been used at the several works of the General Electric Company for several years past with marked success. Its introduction has been responsible for a change in design of some of the lines of apparatus whereby the use of arc welded boiler plate has been substituted in place of cast iron. It is a matter of interest to note that in one of our factories, in 1913, we were using twelve arc welders on thin sheet steel (1/16 in. and 3/32 in.) transformer tanks. The seams were welded by means of carbon arc, there being no metallic electrode welders employed at that time. Today the same factory is using 57 arc welders, 52 using metallic electrodes and 5 using carbon electrodes. Each month these 57

welders consume 1000 carbon pencils, 13,500 lb. of welding wire and 40,000 kw. hr. of electrical energy. They do 67,500 ft. of welding, which works out at an average of 6.2 ft. per hour for each welding operator. This includes a great deal of preparatory work. The speed when actually welding is, of course, much greater. The consumption of electricity averages 0.59 kw. hr. per foot of weld. The consumption of welding wire works out at an average of just about 1 lb. per welding operator per hour. While actually engaged in welding, the consumption is, of course, at a considerably higher rate.

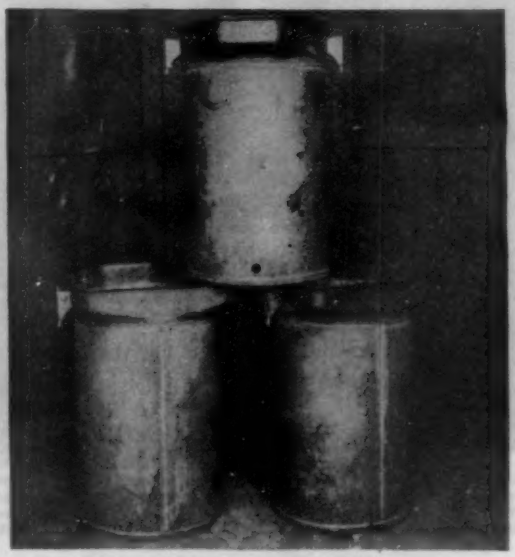

Fig. 3. Sheet Steel Transformer Tank welded with Automatic Arc Welder.

"The following are the different lines of apparatus on which arc welding is being used:

Transformers

"Arc welding is used by us for tanks, transformers, regulators, metering equipments, conservators, transformer breathing pipes, treating and dipping tanks, trucks, racks and bushing adapters. From several years of experience in making oil-tight joints and seams, such as are required on transformer work, we have found that arc welding is about 15 per cent cheaper than riveting. These figures are estimates based upon average conditions. In one of our factories where welding has replaced castings on the tops and bottoms of some of our transformers, we found that a saving of about 25 per cent was made. Figs. 2 to 4 relate to arc welded transformer tanks.

Locomotives

"We are using arc welding for electric locomotive parts, mine

locomotive parts, battery boxes, cabs, gear cases, air compressor frames, air compressor crank shafts and controller frames.

"In this particular line of work, arc welding has taken the place of riveting for motor gear cases, battery boxes, air compressor frames, air compressor crank shafts, controller frames, miscellaneous brackets and cabs. Studs in split gears are secured by the carbon arc. By the use of heavy currents, deep penetration is secured. Gas welding cannot be used on this line of work due to

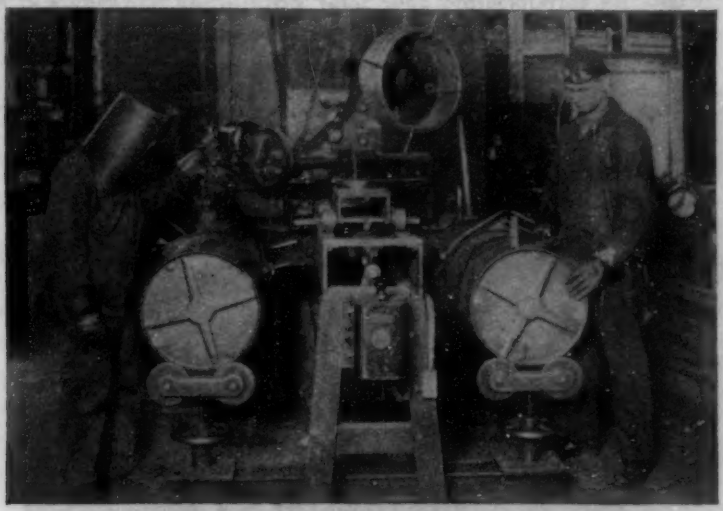

Fig. 4. Automatic Arc Welder. Welding sheet steel transformer tanks. Assembly of tanks also shown. Machine has provision for preparation of work on one side by one man, while on the other side machine is welding work already set up. This cycle is continuous.

the gears being heat treated. The average saving accrued on this line of work is approximately 25 per cent.

Motors

"Automotive motor frames made of $\frac{5}{8}$ in. thick steel plate rolled and welded by the automatic arc welding machine has displaced the steel casting with a saving of $2.00 per frame.

Pole Piece Assembly

"Laminated pole pieces are welded after assembly to prevent their creeping when being drilled and tapped. We have found that this work can be done only with arc welding.

Commutator Shells

"Commutator shells made of stamping steel are assembled by arc welding. Their weight is much less than the cast shell and no machine work is required.

Motor Bases

"Bases for motors and motor-generator sets are made of channel iron and 'I' beams, arc welded together. The outstanding feature

of these bases is light weight, combined with strength and quick assembly. They have replaced the cast iron base. The saving accrued on this kind of work has been 25 per cent.

Motor Fields

"Induction motor field punchings are pressed into a seamless steel tubing and the end rings arc welded, which does away with rivets

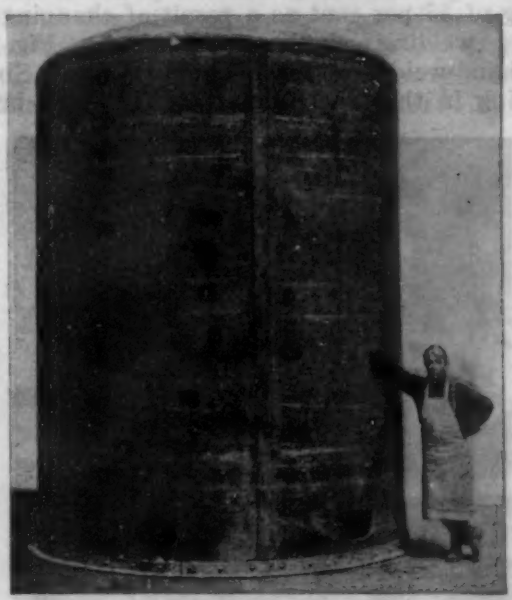

Fig. 5. A 22,000 volt hand-welded oil circuit breaker tank.

through the punchings. While no particular economy in manufacture has been effected, this method results in a better field because the increased compactness does away with loose laminations.

Terminal Boards

"Terminal boards for motors which are arranged for armored conduit connections are assembled together by arc welding due to the high speed of operation.

Generator Stator Frames

Generator stator frames which were made from castings, are now fabricated from steel plate and arc welded. The saving from this change is considerable.

Oil Pans

"Oil pans for vertical waterwheel driven alternators which were made by riveting and soldering to obtain leak-proof joints are now arc welded, and complaints from leaky joints have ceased.

While the saving accrued so far as manufacturing is concerned is small, complaints have been eliminated.

Oil Circuit Breakers

"Oil switch tanks originally made by gas welding were changed to arc welding several years ago when a saving of 20 per cent was effected. After the automatic welding process was introduced on these tanks, an additional 15 per cent saving was effected, making a total saving of 35 per cent as a result of changing from gas to automatic arc welding on these oil tanks. Fig. 5 shows a 220,000 volt hand-welded oil circuit breaker tank. Since introducing arc welding in the construction of oil circuit breakers, steel

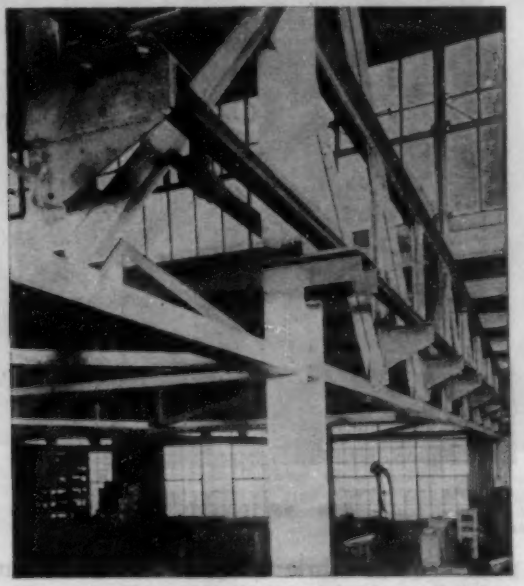

Fig. 6. Attaching crane runway by arc welding.

frame work, sheet steel solenoid housings, galvanized frame work and rotary auxiliary switches are being welded. Supporting pipes for switchboard panels and footplates of pipes for fastening to the floor, were formerly tapped and threaded. These are now being arc welded instead and show a saving of between two cents and three cents each, more than 100,000 being used in a year.

Miscellaneous Tanks

"Tanks of various descriptions used in the factory, such as oil, water, water rheostat and ship regulator tanks, all of which were formerly in most cases riveted, are now being welded and show a saving of approximately 25 per cent.

Miscellaneous Structural Iron

"Fabricated frames for truck panels are mostly arc welded. The exact saving is not obtainable. We are also arc welding a great

deal of structural steel work in several of our factories, the saving in many instances showing at least 15 per cent. Fig. 6 shows the use of arc welding in attaching a crane runway to the steel framework of factory building.

Steel Castings

"Large steel castings for turbine and other work are now being saved and made usable by the use of arc welding. We are unable to estimate the saving effected in this line of work owing to the fact that prior to the use of arc welding many of these castings were rejected and had to be replaced by new castings, there being times when the defects were not discovered until machining

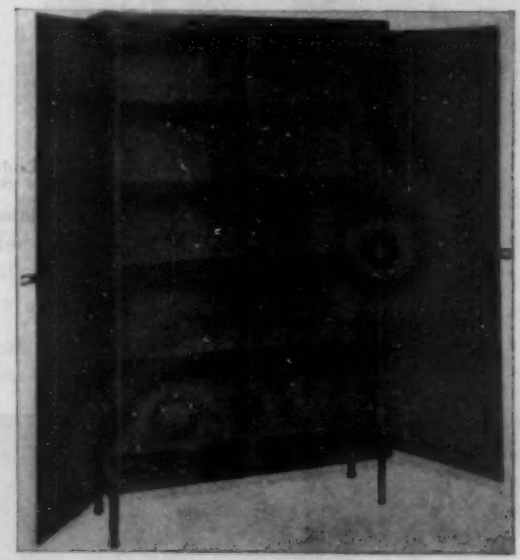

Fig. 7. All Electric Welded Cabinet.

operations had been started. All of this trouble has been eliminated by arc welding.

Miscellaneous Shop Equipment

"Steel racks, lockers, cabinets and shelves are now being welded showing a saving as high as 40 per cent. Fig. 7 shows an arc welded cabinet. Fig. 8 shows a welded steel shop ladder, and Fig. 9 some welded stools.

Furnaces

"Furnaces of different descriptions, previously riveted, are now, in most cases, being electrically welded.

Mercury Boiler

"Mercury boilers, turbines, condensers and accessories. Practically all of this equipment was electrically welded. It is hard to

estimate the amount of money saved by welding, but we feel reasonably sure that without the use of arc welding we would be unable to make some of this equipment leakproof. This was shown in the early stages of the manufacture of the mercury boiler when some of the equipment was riveted and it was found later on that it was necessary to weld these parts in order to make them leak-

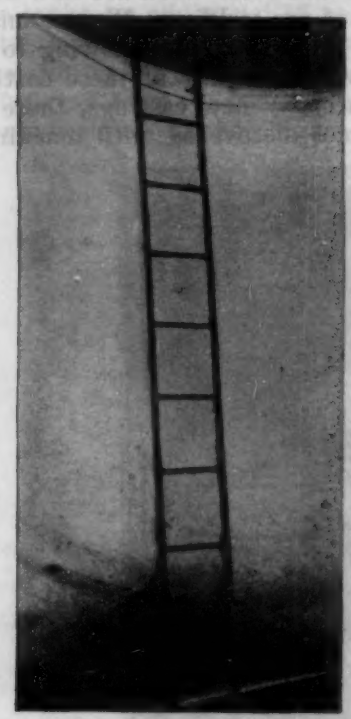

Fig. 8. Steel Shop Ladder, Neat and Strong, Made of Steel Pipe Cut and Arc Welded. Built by Students in Arc Welding School.

proof. Fig. 11 shows the arc welded shell in which the mercury vapor is condensed.

Arc Lamps

"Guide tubes for arc lamps, consisting of a steel tube and malleable iron support are now arc welded. Considerable time and money has been saved by the change from the former method.

Rectifiers

"Armatures for mechanical rectifiers are now being assembled with the use of arc welding, due to the fact that the weight of the component parts must be the same before and after assembly. It is of interest to note that these parts are welded with an electrode about 1/32 in. in diameter, using a current of 8 amperes.

Compressors

"Compressor castings can be welded only by the arc. The chief advantage of welding is the fact that it is relatively easy to make changes and this is not practical with castings.

High Pressure Oil Pipes for Turbines

"Flanges for holding pipes together were originally threaded to the pipe and in some instances welded with gas. By making a slight machine change in the piping and flange, an oil-tight joint can now be made by welding with the arc. Fig. 12 shows a welded

Fig. 9. Steel Shop Chairs made of ¾" Pipe Cut and Arc Welded Together. Built by Students.

strainer for a steam supply line of a high speed turbine. The screen material is monel metal.

Building Up Shafts

"A great many armature shafts used throughout the factory which have become worn at the journal or at the coupling or pulley

Fig. 10. A Large Annealing Cart Completely Electric Welded.

fit are now being welded without stripping the armature, thereby causing an immense saving which is rather hard to estimate.

"In many cases a complete armature is reclaimed by merely building up the shaft. The work has been done automatically.

Copper Hydrogen Brazing Furnaces

"These furnaces used in our factories are now being arc welded, primarily to prevent the leakage of hydrogen gas. We are also tack welding the several parts to hold them together before they are placed in the brazing furnace.

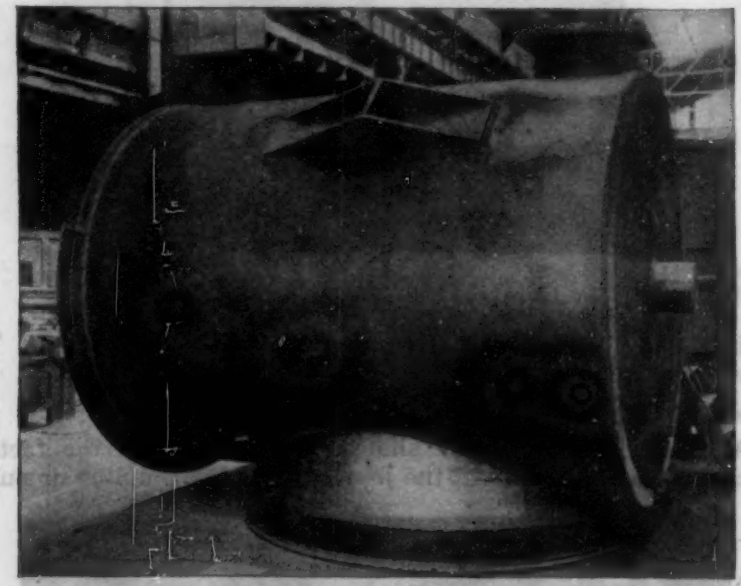

Fig. 11. Special Condenser Boiler Shell. All Seams Electric Arc Welded.

Wire Enameling Machines

"By arc welding, wire enameling machine jackets can be assembled in the towers in about one-half the time that was formerly required.

Flow Meter Nozzles

"The construction of these nozzles when made of steel is such that it is impossible to form them in a die without splitting the flange. This has been overcome by making them in two parts and automatically welding the parts together.

Jigs and Fixtures

"Jigs and fixtures are cut and assembled by arc welding. This does away with an expensive pattern which is used only once. Many times the completed jig costs less than the pattern itself. One important saving in this line of work is time.

Miscellaneous

"Flash backs, manifolds, various pipe connections, and 'Nichrome' Ribbon used for resistors in heating units, are now being

arc welded due to the ease with which the parts can be assembled. Other parts which are being arc welded and upon which we are unable to state the amount of saving are such things as: truck floors, racks, bearing brackets, broken gears, leaky locomotive boiler tubes, broken automotive frames, steel plates for molding insulation, and armature spiders.

"As a general observation gained from our experience in the making of tight joints and seams, such as are required in a great

Fig. 12. Strainers for Turbine Steam Lines. The Inside Screen (A) of Monel Metal is Welded at (1) and (2) with 5/32" Phosphor Bronze and 75 Amperes with Reversed Polarity. The Weld (2) Between Monel Screen (A) and Screen Ring (B) Was Completed in About ½ Hour. The Outside Screen (C) Is of Steel. For One Strainer About 2 lbs. of ¼" Steel Electrode. 1 lb. of Bronze, and About 11 Hours of Labor are Required.

deal of our work, we have found that arc welding is about 15 per cent cheaper than riveting.

"In the welding of thin sheets up to 1/16 in. the cost of gas welding is not any higher than arc welding, while for thicknesses greater than 1/16 in. arc welding is cheaper.

"Satisfactory oil-tight seams cannot be made in steel much thinner than ⅛ in. by riveting. Riveted seams in this thin steel are usually soldered or a gasket is employed to guarantee a tight joint. With the electric arc this is not necessary."

THE USE OF ARC WELDING IN THE WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY'S WORKS

On behalf of the Westinghouse Company Mr. A. M. Candy reports as follows:

"At the Trafford City Works we find that very substantial savings are being made by using the arc welding process on a large variety of tanks, some of which are made for containing transformers and others of which are made for containing oil circuit

breaker mechanism. On a certain size of tank which is 20 in. in diameter and which is manufactured in large quanties, the cost figures indicate that a saving of 40 per cent of the cost is made by using the arc welding process as compared with riveting these tanks together. Furthermore, if the tanks were riveted it would be necessary to weld around the rivets in order to make them oil-tight or else the tank material would have to be made of what is

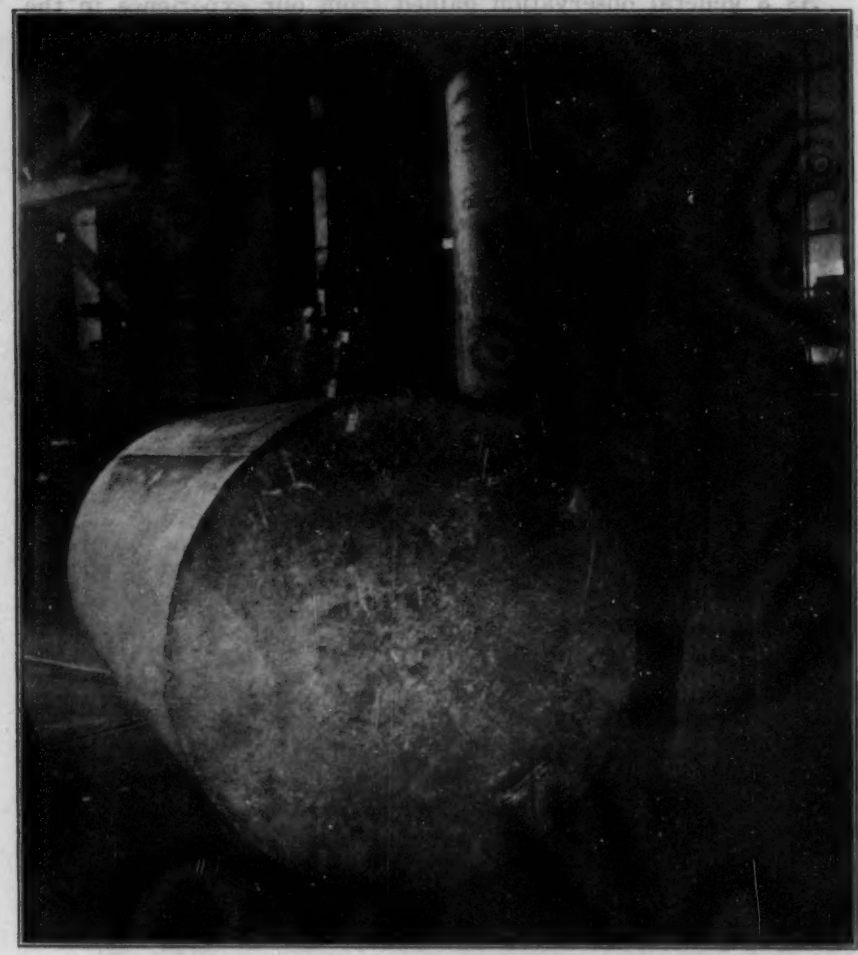

Fig. 13. Large tanks fabricated by arc welding. A much better and cheaper tank is produced by this process.

known as turn plate, so that the joints could be soldered after riveting. (Figs. 13 and 14.)

"On a certain other size of oil breaker tank which is 16 in. in diameter and which is manufactured in quantities, we find that by using the arc welding process instead of riveting we save ¾ of an hour on certain operations which formerly required 2 hours.

"On expansion tanks which are 24 in. in diameter and 60 in. in length, we find that the tank can be manufactured by the arc process for a total cost of $9, whereas the same tank riveted has a cost of approximately $20.

"Gear cases are manufactured by the arc welding process with a saving of 50 per cent of the cost where the riveted construction is used.

"The corrugated cast-in type of transformer tank could not

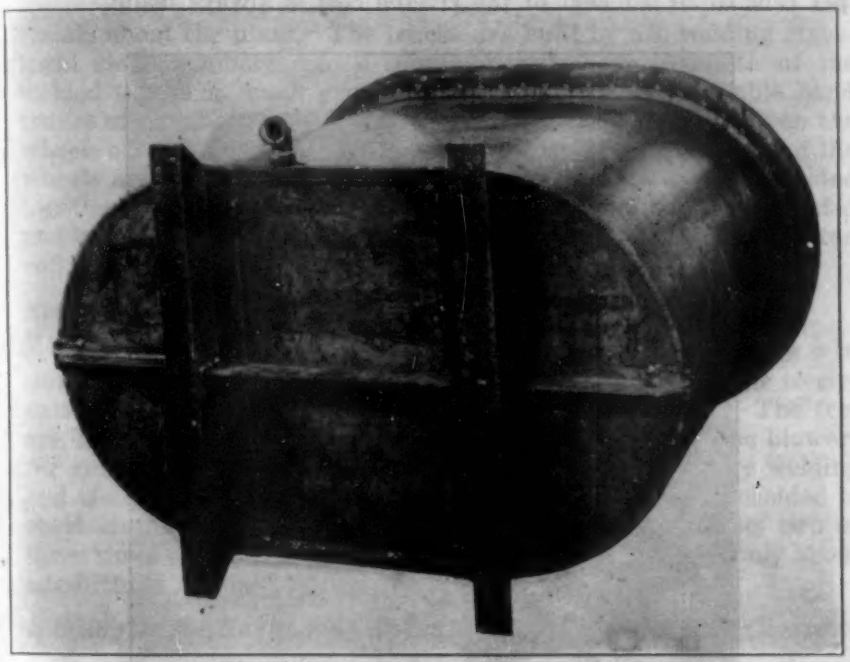

Fig. 14. Large quantities of these transformer tanks are fabricated by arc welding.

be manufactured at all, or at least would be almost prohibitive, if it were not for the welding processes used.

"Elbows for the new type of radiators for transformer tanks are now being constructed from tubing and heavy plate material, using the arc welding process for uniting these parts. This new form of elbow is replacing steel castings which were formerly used, and is showing a saving of 20 per cent of the steel casting cost. Furthermore, the steel castings are very frequently found to be leaky, which in many cases is very difficult to repair, whereas the arc welded elbows are not subject to these difficulties and if a small leak should occur in one of the welds it is quite a simple matter to either do a small amount of additional welding at that point or use a center punch for closing up the hole if it is a small one.

"Some of our smaller tanks, which are made of thin gage stock of the order of No. 16 gage, are manufactured by the arc process at a very appreciable saving over the riveted process, due to the

fact that for such thin stock it is necessary to use turn plate for such construction, using rivets for holding the material together and then soldering the joint. From actual experience it is found that the tanks can be welded for less than the cost of the soldering operation, and it is possible to use black iron, which has only approximately 75 per cent of the cost of the turn plate.

"On all sheet metal work done at the Trafford City Plant where the arc welding process can be applied, a saving of from 15 per cent to 20 per cent of the riveted cost is always made.

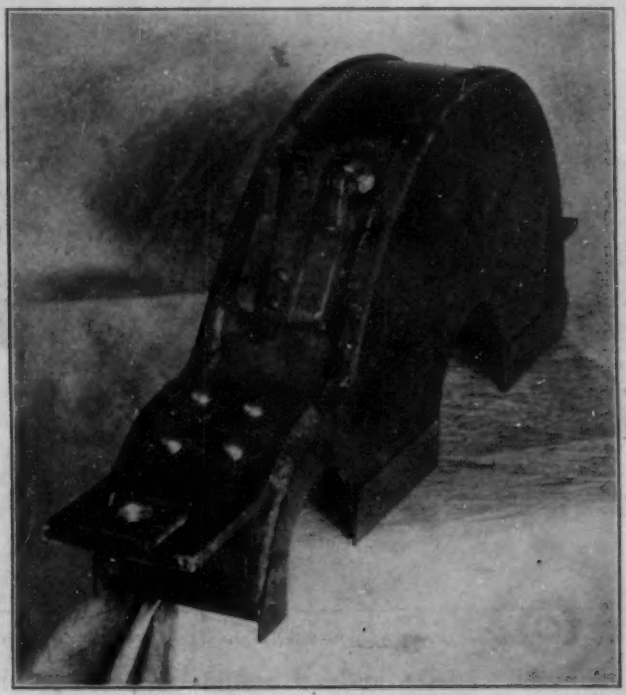

Fig. 15. Gear Cases Fabricated by Arc Welding with a Saving of 50% Over Riveted Construction.

"There are several manufacturing operations being carried on using the welding process, in another of our manufacturing sections. However, it is rather difficult to obtain any definite cost figures owing to the fact that a great deal of their work is now of the rivet-welded construction instead of entirely welded. There is one particular operation, however, namely, that of making the trucks for mounting our arc welding portable single-operator outfits, which are made in relatively large quantities, namely from 25 to 50 and even as high as 75 on an order. The parts for these trucks are assembled and welded completely on a standard time basis of 2 hr., and in many cases the operators are actually able to turn out a truck in 1½ hr. If these same parts are punched and

riveted in this section the time allowance on the job would be 4 hr."

The Use of Electric Arc Welding in the Plant of the Lincoln Electric Co.

Welded Hand Trucks

The Lincoln Electric Co. of Cleveland, has successfully applied welding to the construction of heavy duty hand trucks for portable welders and also for trucks in its factory to transport parts of materials about the plant. The trucks are built by arc welding structural steel members into a complete unit. The strength of the welded trucks is much greater than that of other available hand trucks of equal capacity. They are lighter and cost less. Even the wheels of the steel trucks are made by arc welding. The sides of the wheels are two disks, the tread a circular band with ends welded together to form a ring. At the center a piece of tubing is welded and machined internally to serve as a journal for the axle and ten rollers giving a roller bearing.

Electric Motors

This company now make their motors by using arc welding. In this motor the end is made by rolling a standard steel angle to circular shape, then joining the ends with the arc welder. The feet are drop forged and welded to the angle steel frame. The blowers for ventilation are welded to the rotor or armature by arc welding and lastly, the copper rods or windings of the rotor are welded to short circuit rings. Generally speaking, the casting costs two or three times as much as the steel for the same part and is only about one-fifth as strong.

Welding in the Hawthorne Works of the Western Electric Company

The welding department is fast putting riveting in the discard at Hawthorne. Tanks, angle-iron frames, trucks, doors, scales, window cabinets, metal furniture and structural steel shapes, which formerly required riveting, are now being put together without a single rivet. The old method of making gear guards for machinery by riveting sheet iron to a piece of angle-iron, previously shaped by the blacksmith, cost approximately twice as much as the welding process.

Six welding units were installed to do nothing else but turn out machine switching frames.

Acknowledgments

The authors wish to acknowledge their indebtedness to Mr. W. L. Warner for the assistance he has rendered in furnishing data and information in many parts of this paper, and to Mr. M. A. Atuesta of the General Electric Co., and Mr. A. M. Candy of the Westinghouse Electric and Manufacturing Co., for their reports covering the applications of welding in their respective companies.

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Use Electric Arc in All Welded Steel Building, J. W. Turner, Canadian Machinery and Manufacturing News (May 29, 1925), Vol. 33, pp. 29-30. Advantages of method, even sash welded.

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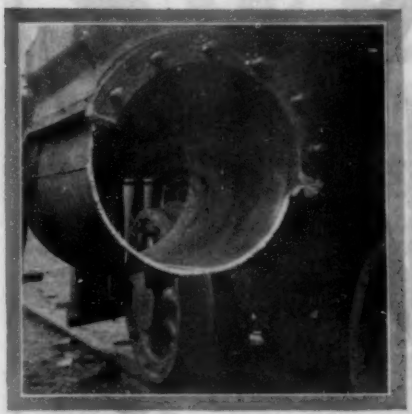

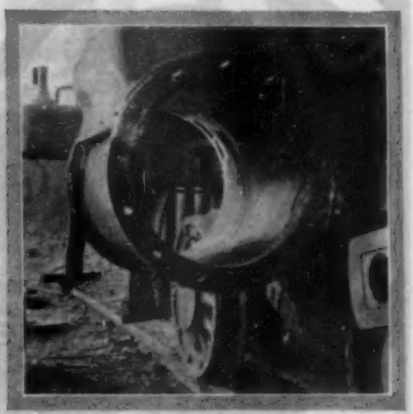

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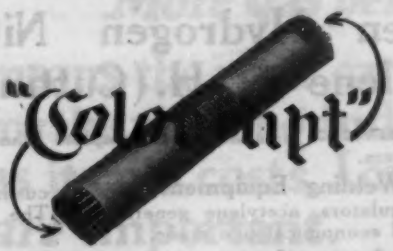

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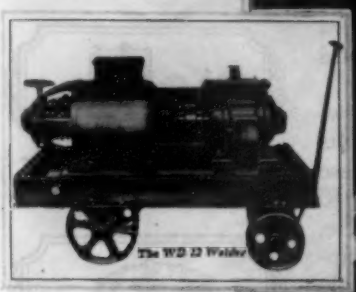

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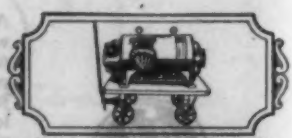

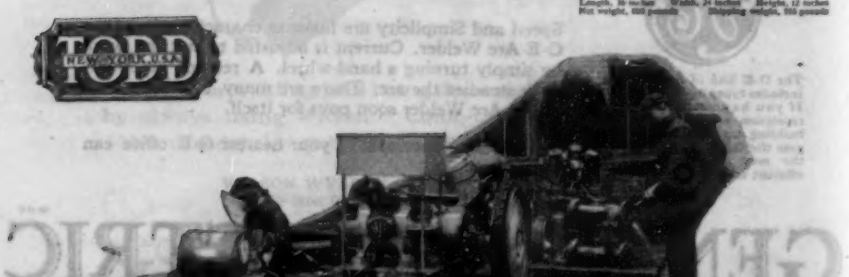

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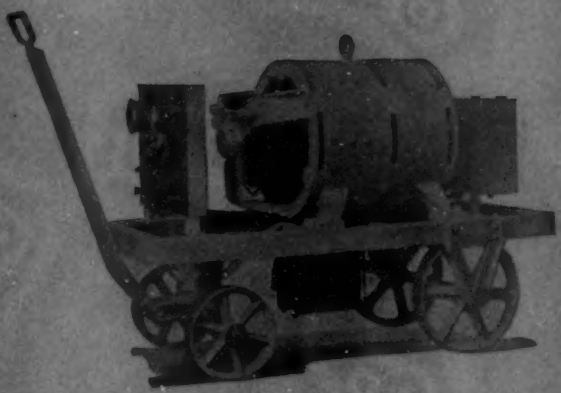

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